PB84-161405

Operation and Maintenance of Publicly-Owned Treatment Works (POTW´s). Proceedings of the EPA National Conference Held at Chicago, Illinois on January 12-14, 1982

Weston (Roy F.), Inc., West Chester, PA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Dec 83

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/9-83-021
December 1983

Research and Development

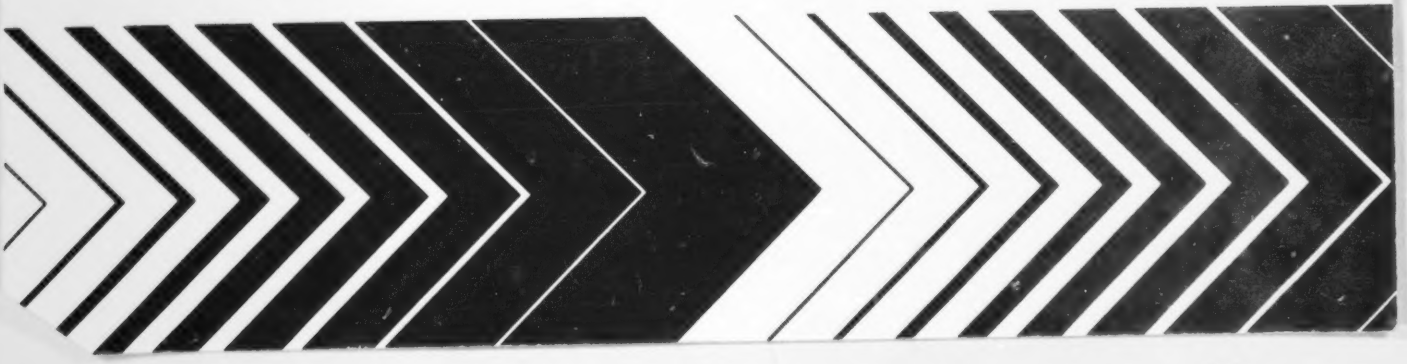
PB84-161405

EPA

Operation and Maintenance of Publicly-Owned Treatment Works (POTW's):

Proceedings of the EPA National Conference

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161



TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/9-83-021

2.

3. RECIPIENT'S ACCESSION NO.
PB84 161405

4. TITLE AND SUBTITLE
EPA National Conference Proceedings on the Operation and Maintenance of Publicly-Owned Treatment Works (POTW's)

5. REPORT DATE
December 1983

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Roy F. Weston, Inc.
Weston Way
West Chester, PA 19380

10. PROGRAM ELEMENT NO.
AZB1B

11. CONTRACT/GRANT NO.
68-03-3055

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory - Cin., OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

13. TYPE OF REPORT AND PERIOD COVERED
Proceedings

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Project officer: Gary R. Lubin (513)684-7630

16. ABSTRACT

This proceedings is a compilation of the papers presented at EPA's National Conference on the Operation and Maintenance of POTW's held in Chicago, Illinois on January 12-14, 1982. The purpose of the conference was to present information on improved POTW operation, maintenance, design, performance and energy effectiveness. Most of the information presented at this conference was based upon results from research funded through the Plant Operation and Design Program of EPA's Municipal Environmental Research Laboratory, Wastewater Research Division in Cincinnati, Ohio.

This proceedings is intended to provide a permanent record of the information presented at this conference and to make those involved in POTW operation, maintenance, and design aware of the type of research funded through EPA's Plant Operation and Design Program. The conference was organized into five different sessions corresponding to major areas of program interest.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT
Release to Public

19. SECURITY CLASS *(This Report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES
269

22. PRICE

EPA-600/9-83-021
December 1983

OPERATION AND MAINTENANCE OF PUBLICLY-OWNED TREATMENT WORKS (POTW's)

PROCEEDINGS OF THE EPA NATIONAL CONFERENCE

Chicago, Illinois
January 12-14, 1982

Sponsored by the

Municipal Environmental Research Laboratory
and
Center for Environmental Research Information
U.S. Environmental Protection Agency

Administered by

Roy F. Weston, Inc.
West Chester, Pennsylvania 19380

Contract No. 68-03-3055

Project Officer

Gary R. Lubin
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency.

FOREWORD

The Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is the first necessary step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and the solid and hazardous waste pollutant discharges from municipal and community sources; to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health and aesthetic effects of pollution. This publication is one of the products of that research--a vital communications link between the researcher and the user community.

These Proceedings present information on improved POTW operation, maintenance, design, performance and energy effectiveness.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

PREFACE

This proceedings is a compilation of the papers presented at EPA's National Conference on the Operation and Maintenance of POTW's held in Chicago, Illinois on January 12-14, 1982. The purpose of the conference was to present information on improved POTW operation, maintenance, design, performance and energy effectiveness. Most of the information presented at this conference was based upon results from research funded through the Plant Operation and Design Program of EPA's Municipal Environmental Research Laboratory, Wastewater Research Division in Cincinnati, Ohio.

This proceedings is intended to provide a permanent record of the information presented at this conference and to make those involved in POTW operation, maintenance, and design aware of the type of research funded through EPA's Plant Operation and Design Program. The conference was organized into five different sessions corresponding to major areas of program interest.

All of the papers and final reports resulting from the research funded by the Plant Operation and Design Program are listed in a separate reference section of this proceedings. Copies of the material listed in the reference section are not generally available through the Environmental Protection Agency. Most of these references are only available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161 unless they are part of a published periodical.

TABLE OF CONTENTS

	TITLE	PAGE
Foreword		iii
Preface		iv
Session No. 1	O&M of Wastewater Treatment Processes	1
Paper No. 1	"Results of National O&M Cause and Effect Survey," Bob A. Hegg	1
Paper No. 2	"A Model Protocol for the Comprehensive Evaluation of POTW's," Albert C. Gray and Hugh D. Roberts	14
Paper No. 3	"Operation and Maintenance Considerations of Land Treatment Facilities," Kimm Perlin	42
Session No. 2	Improving the Performance of Conventional Wastewater Treatment Processes	63
Paper No. 4	"Making-Do with Clarifier Hydraulic Overload," Robert M. Crosby	63
Paper No. 5	"Minimizing Impact of Side Streams on Total Plant Performance," Roy O. Ball	78
Paper No. 6	"Composite Correction Program - Concepts and Demonstration," Bob A. Hegg	95
Paper No. 7	"Application of Intrachannel Clarifiers in the Oxidation Ditch Process," Harold J. Beard	105

TABLE OF CONTENTS
(Continued)

	TITLE	PAGE
Paper No. 8	"Biological Fouling of Fine Bubble Diffusers," William C. Boyle and David T. Redmon	119
Session No. 3	Improving Process Reliability	136
Paper No. 9	"Stability and Reliability of Biological Processes," Edward D. Schroeder and Salar Niku	136
Paper No. 10	"Evaluation and Documentation of Mechanical Reliability of Conventional Wastewater Treatment Plant Components," David W. Shultz and Van B. Parr	159
Paper No. 11	"Fail Safe Design Concepts," Roy O. Ball	171
Session No. 4	Improving POTW Design	176
Paper No. 12	"Design Deficiencies in POTW's," Roy O. Ball	176
Paper No. 13	"Performance Capabilities and Design of Oxidation Ditch Processes," William F. Ettlich	182
Paper No. 14	"Performance and Design of RBC Processes," Warren H. Chesner	195
Session No. 5	Energy Conservation in Municipal Wastewater Treatment	201
Paper No. 15	"Energy Conservation in Unit Processes and Sludge Management," Daniel Cortinovis	201
Paper No. 16	"A Composite Approach to Energy Conservation Through Process Optimization - Some Case Studies," Ashok K. Singhal, Phillip N. Loud and Donald W. Lystra	210

TABLE OF CONTENTS
(Continued)

	TITLE	PAGE
Paper No. 17	"Alternative Energy Sources in Municipal Wastewater Treatment: the Wilton, Maine Experience," David R. Fuller	232
Reference Section:	Plant Operation and Design Program - Related Publications and Papers	255

SESSION NO. 1
O&M of Wastewater Treatment Processes

PAPER NO. 1

RESULTS OF NATIONAL O&M CAUSE AND EFFECT SURVEY

by

Bob A. Hegg
Vice President Plant Operations Division

M & I, Inc., Consulting Engineers
4710 South College Avenue
Fort Collins, Colorado 80525

RESULTS OF NATIONAL O & M CAUSE AND EFFECT SURVEY

Bob A. Hegg , Vice President Plant Operations Division
M & I, Inc., Consulting Engineers

INTRODUCTION

The Federal Water Pollution Control Act with Amendments established goals for the quality of the nation's public waters. A major aspect of the act was an expanded construction grants activity through which new wastewater treatment facilities were constructed and existing facilities upgraded. However, the U.S. Environmental Protection Agency's (EPA) annual reports to Congress (1) have indicated that a significant number of the facilities constructed with Federal grant assistance have not provided the desired effluent quality. Other reports and articles have supported these conclusions (2, 3, 4).

In response to these findings, EPA's Office of Research and Development initiated a three and one-half year research program to identify, quantify and rank the factors causing poor wastewater treatment plant performance. M & I, Inc., Consulting Engineers was selected to complete the two-phase project in the Western United States. To accomplish the research objectives, comprehensive plant evaluations were conducted in facilities in nine Western states. Initially, 271 facilities were considered for study. Ninety-eight were visited and fifty were selected for comprehensive studies (5, 6, 7).

RESEARCH APPROACH

The major objective of the project was to identify and rank the factors causing poor wastewater treatment plant performance. Because a limited number of facilities were studied, a specialized plant selection procedure was established. The major target of facility selection was plants that were supposedly developed to meet specific treatment requirements. As such, "operable plants" which were loaded within currently used design criteria, which were operated using reasonable staffing levels and were not having major equipment problems with critical process units were selected. Additional selection criteria limited the facilities to biological wastewater treatment plants with flows less than 37,850 cum/day (10 mgd) and to plants not involved in enforcement action.

EPA Regions VII and VIII and nine state regulatory agencies were informed of the plant selection criteria. These agencies suggested a total of 271 facilities for research. Of the facilities suggested, half-day site visits were conducted at 98 facilities. Fifty of these facilities were selected for the more comprehensive studies. Both plants that were meeting treatment requirements and plants that did not meet requirements were selected.

The comprehensive plant evaluations were typically conducted with one and one-half to two man-weeks of effort over a four to ten-day period.

Persons conducting the surveys were sanitary engineers with experience in plant operations and in identifying and evaluating performance-limiting problems. During each evaluation the research team worked with plant personnel to eliminate any obvious and controllable performance-limiting problems. This action-oriented, assistance approach to data gathering necessitated open communication between plant personnel and research personnel. As such, a service to the plant owner was provided while more accurate and less apparent research information was collected.

Each in-plant evaluation was followed by a written report which documented the problems identified. Recommendations to the city or sanitation district were offered, but implementation of these was voluntary.

Problems limiting plant performance were evaluated using a list of 71 pre-defined factors. Each factor was assigned from zero to three points in proportion to the adverse effects that factor had on an individual plant's performance. The results from all individual surveys were combined to obtain an overall ranking of these factors.

PRESENTATION OF DATA

Only 13 of 50 facilities surveyed consistently met minimum secondary treatment standards as defined in CFR 38-159. The mean hydraulic loading on all plants surveyed was 66 percent of design flow. The mean hydraulic loading for the 37 facilities that violated standards was also 66 percent of design flow. These loadings were in line with plant selection criteria, in that the plants studied were within design limits and supposedly were capable of meeting required effluent standards.

Table 1 shows the ranking of all 71 factors for the 50 facilities evaluated. The number of times each factor occurred is also shown. An average of 13 and a range of 4 to 30 performance-limiting factors were documented at individual facilities. Many different performance-limiting factors were noted, and no two facilities had an identical combination of factors.

The two highest ranking factors were inadequate operator application of concepts and testing to process control and inadequate sewage treatment understanding. These findings indicate that many operators were not adequately trained. It could be concluded that expanded training programs are necessary, but it was observed that "trained" operators did not properly apply concepts of operation to process control. Therefore, expanded training appears necessary, but modifications to existing programs are needed. Any attempt to modify and improve training must include a full awareness of the number three ranked factor, improper technical guidance concerning plant operations. Improper technical guidance was documented from authoritative sources including design engineers, state and federal regulatory personnel, operator training program staff, other plant operators and equipment suppliers.

These findings indicate that other sources have limited the capability of operators: first to attain adequate sewage treatment understanding and

TABLE 1. RANKING OF FACTORS LIMITING PERFORMANCE

Item No.	Ranking Total Pts.	Factor Limiting Performance	No. of Times Factors Occurred	Total Pts.
1	1	Operator Application of Concepts and Testing to Process Control	48	96
2	2	Sewage Treatment Understanding	28	55
3	3	Technical Guidance	25	54
4	4	Sludge Wasting Capability	26	51
5	5	Process Control Testing	32	47
6	5	Process Controllability	32	47
7	7	Process Flexibility	24	45
8	8	Aerator	17	35
9	8	Infiltration/Inflow	24	35
10	10	Clarifier (Secondary)	16	28
11	11	Ultimate Sludge Disposal	19	27
12	12	Sludge Treatment	19	24
13	13	Familiarity with Plant Needs (Adminstrators)	11	20
14	14	Performance Monitoring	16	18
15	15	Policies (Administrators)	10	17
16	15	Laboratory Space and Equipment	16	17
17	15	Disinfection	11	17
18	18	Plant Coverage	15	16
19	19	Unit Process Layout	7	15
20	19	Preliminary (Design)	15	15
21	21	Working Conditions	12	14
22	22	Equipment Malfunction	8	13
23	22	Alternate Power Source	13	13
24	22	Alarms Systems	13	13
25	25	Motivation (Operators)	12	12
26	25	Number (Staff)	11	12
27	27	Scheduling and Recording (Maintenance)	11	11
28	27	Adequacy (O & M Manual)	10	11
29	27	Productivity (Operators)	9	11
30	27	Aptitude (Operators)	8	11
31	31	Return Process Streams	7	10
32	31	Training Operators	9	10
33	33	Industrial (Loading)	6	9
34	33	Insufficient Funding	9	9
35	33	Housekeeping	8	9
36	33	Pay (Operators)	7	9
37	37	Plant Inoperability Due to Weather	6	8
38	38	Lack of Unit Bypass	7	7
39	38	Flow Proportioning to Units	6	7
40	38	Supervision	5	7
41	41	Level of Certification	6	6
42	41	Equipment Age	6	6
43	41	Insufficient Time on Job	5	6
44	41	Lack of Program (Maintenance)	5	6
45	41	Manpower (Maintenance)	5	6
46	46	Unnecessary Expenditures	5	5
47	46	Spare Parts Inventory	5	5
48	46	Flow Backup	3	5
49	49	Plant Management	2	4
50	49	Plant Location	3	4
51	51	Hydraulic (Loading)	3	3
52	52	Toxic (Loading)	2	2
53	52	Seasonal Variation (Loading)	2	2
54	52	Process Accessibility for Sampling	2	2
55	52	Lack of Standby Units for Key Equipment	2	2
56	52	Process Automation Control	2	2
57	52	O & M Manual, Use by Operators	2	2
58	58	Quality of Equipment	1	1
50	58	Level of Education	1	1
60	58	Organic (Loading)	1	1
61	58	Submerged Weirs	1	1
62	58	Personnel Turnover	1	1
63	63	Bond Indebtedness	0	0
64	63	References Available	0	0
65	63	Staff Expertise (Emergency Maintenance)	0 0	0 0
66	63	Critical Parts Procurement	0	0
67	63	Technical Guidance (Emergency Maintenance)	0	0
68	63	Unit Design Adequacy, Primary	0	0
69	63	Process Automation, Monitoring	0	0
70	63	Equipment Accessibility for Maintenance)	0	0
71	63	Shift Staffing Adequacy	0	0

second to apply this understanding to process control. Just as important, the improper technical guidance and associated lack of understanding by authoritative personnel has carried over into plant design. Five of the top ten factors limiting performance were process design oriented. These areas of inadequate design in order of severity were: sludge wasting capability, process controllability, process flexibility, aerator and secondary clarifier. The inability of persons involved with plant design to properly apply the technology necessary to develop adequate treatment facilities, coupled with the improper operations technical guidance from these and other sources, indicates that the plant performance problem is widespread and not limited to strictly plant personnel.

This analysis of the top ten performance-limiting factors indicates that problems limiting facility performance are interrelated, and a straight forward approach to improved performance by addressing these factors is not readily apparent. Other evaluations of selected individual factors support this conclusion. The approach used to evaluate other factors was to relate the potential problem area to plant performance. Several prominently discussed factors were evaluated using this approach: plant staffing, operator salaries, aerator size and operator certification.

Figure 1 shows staff size plotted versus plant flow rate. As shown by the least squares line of best fit, staff size increased with plant flow. The thirteen fully shaded dots represent the plants where secondary treatment standards were met. If a larger number of operations personnel was

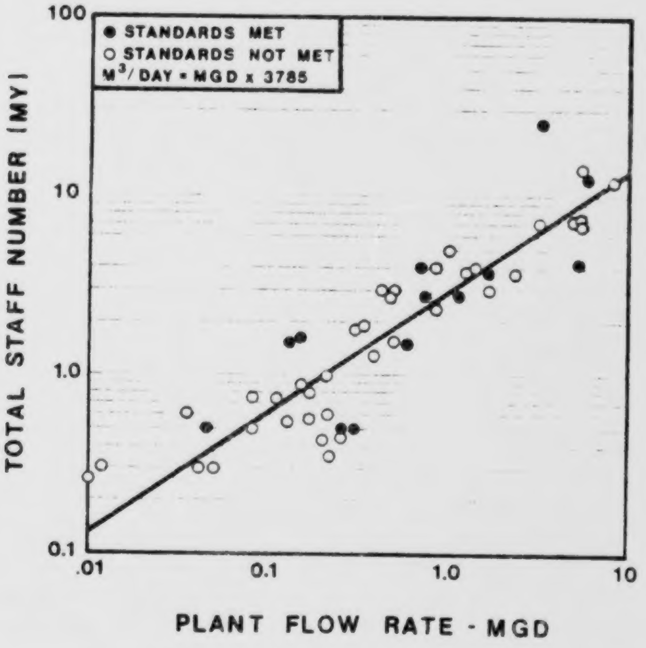


Figure 1. Staff Size versus Plant Flow Rate

the key to the solution of the plant performance problem, shaded dots representing plant where standards were met would tend to be located above the line of best fit. Six of thirteen points are below the line, and a correlation between plant staffing and performance could not be made.

A similar analysis was performed for staff salaries. As shown in Figure 2, higher salaries did not appear to correlate directly with better treatment.

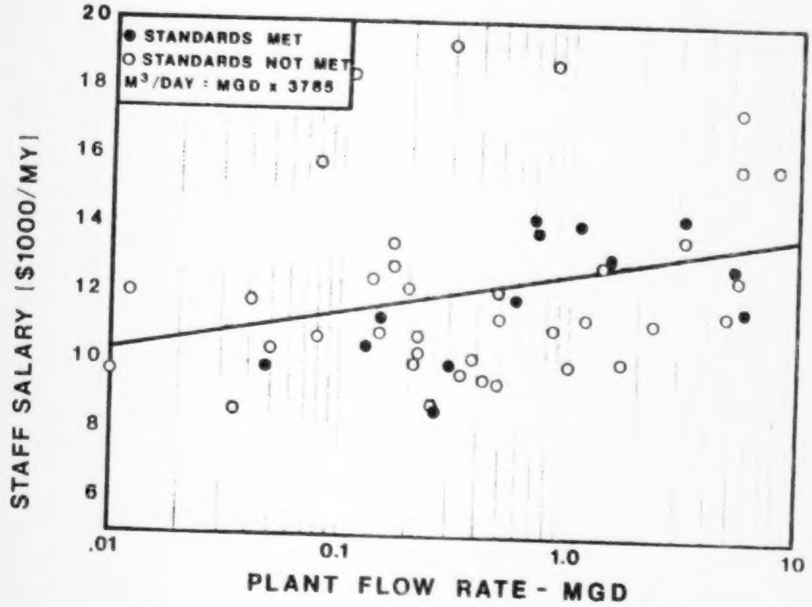


Figure 2. Staff Salary versus Plant Flow Rate

Aerator loadings in pounds of BOD$_5$ per day per 1000 cubic feet are presented in Figure 3. As used here, "aerator" refers to the facility utilized for the conversion of soluble organic matter into settleable organic matter. Examples of aerators are trickling filters, activated sludge aeration basins and activated bio-filters. The extreme scatter of data did not lend itself to a line of best fit; however, aerator loading appears to increase gradually as plant flow rate increases. Nine of the thirteen plants that met standards had low aerator loadings, less than 15 lb BOD$_5$/day/1000 cu ft. A premature conclusion could be that low aerator loadings are a key to improved performance, and therefore more conservative design criteria are needed. However, just as many facilities with low aerator loadings violated secondary effluent standards. A conservative design approach may help, but it is not reliable in achieving desired performance. It is also suggested that improved performance through very conservative design is not the most cost effective alternative.

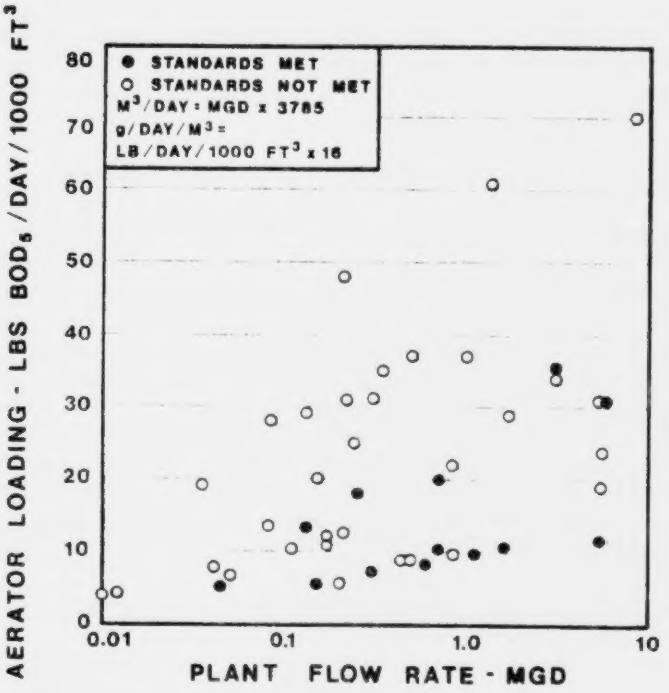


Figure 3. Aerator Loading versus Plant Flow Rate

The relationship between operator certification and plant performance is summarized in Table 2. Only 40 percent of the facilities which had "A" and "B" certified operators were found to be meeting effluent standards.

This was a higher percentage than for the lower and noncertified operator's facilities. Certification of treatment plant operators seems to be a step in the right direction, but it too does not appear to be the total answer.

TABLE 2. EVALUATION OF OPERATOR CERTIFICATION VERSUS PLANT PERFORMANCE

Certification Class Of Chief Operator*	Number of Facilities Surveyed	Secondary Treatment Standards		
		Met	Violated	%Met
"A"	15	6	9	40
"B"	10	4	6	40
"C"	9	1	8	11
"D"	9	1	8	11
None	7	1	6	14

*"A" is equivalent to the highest certification rating.

Evaluation of the data collected indicated that each facility was typically limited from achieving good performance by a combination of factors unique to that facility. Evaluations of high ranking factors did not lead to any positive conclusions regarding methods to improve individual plant performance on a broad scale.

UNIFIED CONCEPT FOR ACHEIVING OPTIMUM PLANT PERFORMANCE

Many programs and activities are available that deal with correcting the performance limiting factors at wastewater treatment facilities. Examples are operator training schools, operator certification programs, the NPDES permit program, Federal and State construction grant programs, design seminars, O & M manuals, and regulatory agency inspections. All of the facilities evaluated had participated in one or more of these activities; however, in most cases the implementation of these programs did not result in a particular plant achieving a desired level of performance. Apparently, the combinations of factors unique to each facility were not compatible with or were not adequately addressed by the programs that had been implemented, and several performance-limiting factors continued to degrade plant effluent quality.

The interrelationship between factors limiting performance and possible solutions was further defined for the research project in a "Unified Concept for Achieving Optimum Plant Performance." The Concept is illustrated in Figure 4. The goal is to obtain an optimum performance level for

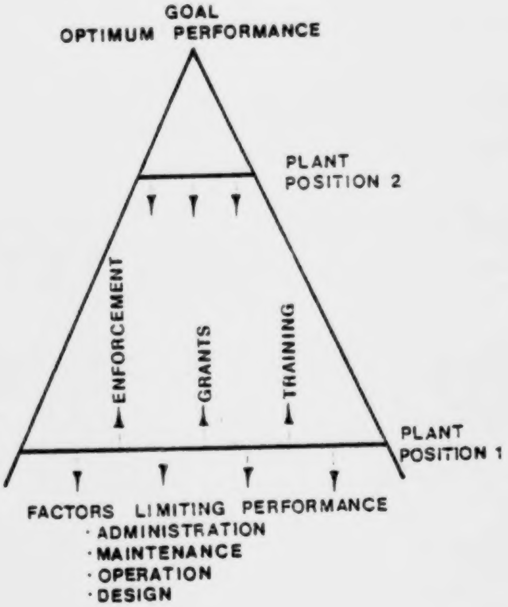


Figure 4. Unified Concept

a given treatment plant. The horizontal line represents the position of a treatment facility with respect to optimum performance. The length of the horizontal line represents the combined magnitude of all factors limiting performance at that plant. Administrative, maintenance, operation and/or design factors that limit performance tend to increase the length of the horizontal line and move a plant away from the goal (Plant Position 1). These factors are indicated by the number and length of arrows pointing downward.

Performance limiting factors are typically addressed through implementation of programs such as enforcement, a construction grant, an operator training program, etc. Correction of a factor or group fo factors moves a plant's position closer toward the goal of optimum performance. However, if all the performance-limiting factors are not addressed, the plant will only move to Position 2. At Position 2 the length of the horizontal line is shorter indicating fewer or less severe performance-limiting factors remain, but optimum performance has not been achieved and effluent quality may or may not meet requirements.

The Concept can be illustrated with an example. Assume that a plant's performance was severely limited (Position 1) by two factors: a hydraulic overload and poor process control. If the plant's overload problem was corrected through a plant modification supported by a construction grant but poor process control continued, the plant's position would improve (Position 2) but the plant would not achieve optimum performance. This example illustrates why many programs have not been able to achieve desired performance at a particular facility: all the factors significantly limiting performance at that facility were not corrected.

COMPOSITE CORRECTION PROGRAM

Ideally, optimum performance can be achieved only if all of the factors limiting performance are corrected. This objective can be more directly and positively addressed by implementing a single comprehensive program at each facility. In such a manner, the comprehensive program can address the factors limiting performance unique to that facility. This approach has been termed a Composite Correction Program (CCP) and is conceptually illustrated in Figure 5.

As illustrated, a CCP addresses all the performance-limiting factors at a particular facility (Plant Position 1), and can thus ideally achieve optimum plant performance. To demonstrate this approach, a CCP was implemented at Havre, Montana, as a part of the research project. A separate report was prepared describing the implementation and results (6). Plant effluent BOD_5 and TSS concentrations are shown in Figure 6, and are indicative of the capability of the CCP approach to improve performance of an individual facility plagued by various unique combinations of factors.

A CCP could not be implemented at all of the facilities surveyed because the combination of factors limiting performance was not usually amenable to correction within the budget constraints of the research project. However, sufficient data was collected at each research facility

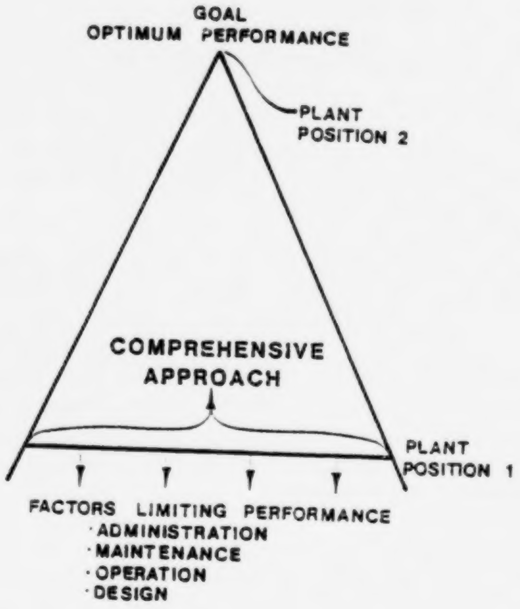

GOAL
OPTIMUM PERFORMANCE
PLANT POSITION 2
COMPREHENSIVE APPROACH
PLANT POSITION 1
FACTORS LIMITING PERFORMANCE
·ADMINISTRATION
·MAINTENANCE
·OPERATION
·DESIGN

Figure 5. Unified Concept - Composite Correction Program

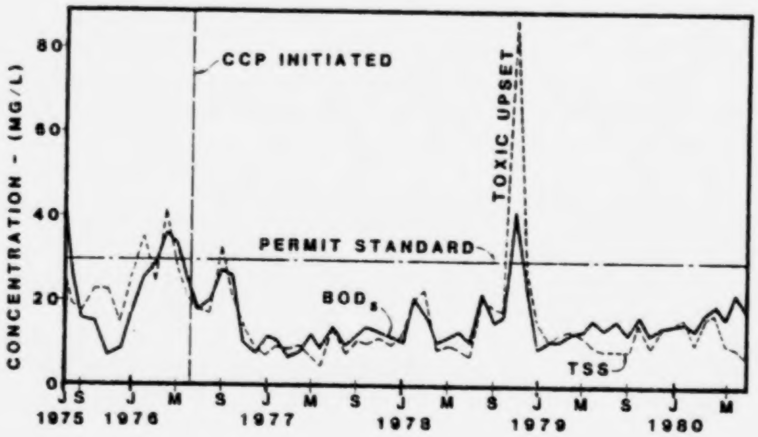


Figure 6. Results of CCP approach - Havre, Montana

to project the probable results of implementing a CCP. A dramatic improvement in overall performance would occur. Table 3 presents a summary of the performance of the fifty facilities evaluated in relation to secondary treatment standards. CCP's without major facility upgrades could allow 27 additional plants to meet secondary treatment. Ten plants would require a major upgrade as part of the CCP in order to meet secondary standards.

TABLE 3. PERFORMANCE OF FIFTY PLANTS EVALUATED VERSUS SECONDARY TREATMENT STANDARDS

	Prior to Research	Potential After CCP*
Standards Violated	37	10
Standards Met	13	40

*In this evaluation the option of a major facility upgrade was excluded as a portion of the CCP.

An evaluation of all facilities surveyed showed that the performance of 38 facilities could be improved using the CCP approach (excluding major facility modifications). The projected average improvement in effluent quality was 25 mg/l for BOD_5 (59 percent decrease) and 46 mg/l for TSS (63 percent decrease).

The CCP approach provides a viable method for improving plant performance at individual treatment facilities and should be implemented on a broad scale. However, incentives are needed to encourage the use of CCP's, and qualified personnel are required to implement CCP's (5, 6). Personnel who implement CCP's must be able to recognize and prioritize actual performance-limiting factors in the broad areas of design, operation, maintenance and administration. These persons must then be in a position to implement recommendations over a long enough time period to insure that desired performance is achieved and maintained. A properly implemented CCP utilizes all available resources to economically correct the unique combination of factors limiting performance at a particular facility.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions of the research effort were separated into two categories: conclusions on all facilities and conclusions concerning individual treatment plants. For all facilities, it was determined that individual facilities are hindered from achieving desired performance by multiple factors unique to each facility. As such, specific programs implemented to address selected factors at all facilties will have a limited correlation between program implementation and improved performance at individual plants. This conclusion is significant in that large scale programs normally are assessed on their most obvious intended impact. It is thus conceivable that programs could be excluded from development or eliminated because of their inability to show a direct correlation between program implementation and improved plant performance. Yet these programs may be very necessary to address the high ranking and frequently occurring performance limiting factors identified.

For individual plants it was concluded that multiple and unique factors limit a facility's performance. The scope of these factors is often beyond the plant operator's control (i.e., improper technical guidance and design deficiencies). To achieve a direct correlation between an individual plant's performance and program implementation, a comprehensive site-specific effort is required.

Based on the above conclusion, the following recommendations were developed.

- All Facilities - Implement programs to address identified high priority factors. Implementation must be achieved with a full awareness of the difficulty in directly assessing impact.
- Individual Facilities - Implement programs to support initiation of comprehensive site-specific efforts (CCP's) at individual facilities. For example, enforcement for noncomplying facilities could be used to encourage CCP activities.

ACKNOWLEDGEMENTS

The data upon which this publication is based was compiled pursuant to Contract Nos. 68-03-2224 and 68-03-2572 with the Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio. The guidance and assistance from Mr. John M. Smith, who served as project officer for the Environmental Protection Agency, is gratefully acknowledged. The cooperation and assistance provided by federal, state and local water pollution control agencies is also gratefully acknowledged.

REFERENCES

1. "Clean Water Report to Congress - 1973, 1974, 1975 Annual Reports", U.S. Environmental Protection Agency, Washington, D.C., May 1973, June 1974, June 1975.

2. Gilbert, Walter G.,"Relation of Operation and Maintenance to Treatment Plant Efficiency", Journal of Water Pollution Control Federation, 48, 1822 (1976).

3. "Continuing Need for Improved Operation and Maintenance of Municipal Waste Treatment Plants", Report to the Congress by the Comptroller General of the United States, Washington, D.C., (April 11, 1977).

4. "Costly Wastewater Treatment Plants Fail to Perform As Expected", Report to the Congress by the Comptroller General of the United States, Washington, D.C., (November 14, 1980).

5. Hegg, B.A., K.L. Rakness and J.R. Schultz, "Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant

Performance", EPA-600/2-79-034, NTIS No. PB-300331, U.S. Environmental Protection Agency, Cincinnati, Ohio (1979).

6. Hegg, B.A., K.L. Rakness and J.R. Schultz, "A Demonstrated Approach for Improving Performance and Relaibility of Biological Wastewater Treatment Plants", EPA-600/2-79-035, NTIS No. PB-300476, U.S. Environmental Protection Agency, Cincinnati, Ohio (1979).

7. Hegg, B.A., K.L. Rakness and J.R. Schultz, "Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance - Phase II", EPA-600/2-80-129, NTIS No. PB-81-112864, U.S. Environmental Protection Agency, Cincinnati, Ohio (1980).

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

PAPER NO. 2

A MODEL PROTOCOL FOR
THE COMPREHENSIVE EVALUATION
OF PUBLICLY OWNED TREATMENT WORKS

by

A. C. GRAY
Project Manager

and

H. D. ROBERTS
Project Engineer

Gannett, Fleming, Corddry & Carpenter, Inc.
P.O. Box 1963
Harrisburg, Pennsylvania 17105

A MODEL PROTOCOL FOR COMPREHENSIVE EVALUATION OF PUBLICLY OWNED TREATMENT WORKS

Albert C. Gray and Hugh D. Roberts , Project Manager and Project Engineer
Gannett, Fleming, Corddry & Carpenter, Inc.

INTRODUCTION

Findings of EPA sponsored studies conducted during the 1970's indicate that: a) at least 50 percent of the publicly owned treatment works (POTW's) constructed under the federal construction grants program (PL 92-500) are not achieving permit compliance (1); b) poor plant performance is usually due to a combination of inhibitory factors (2, 3); c) implementation of a composite correction plan (CCP) could bring the great majority of these plants into compliance without requiring major plant expansion or upgrading. The key to developing an effective CCP is the performance of a comprehensive plant evaluation which results in the identification of performance limiting factors and an analysis of the degree to which each factor impacts treatment efficiency. An effective plant evaluation will provide the basis for prioritization of requisite corrective measures which then can be implemented to bring about treatment performance improvements in a timely, cost effective manner. Conversely an improperly conducted evaluation can result in wasted time and effort in implementing inappropriate corrective procedures.

In the course of conducting research to determine factors limiting performance of biological treatment plants in the eastern U.S., 53 detailed plant evaluations were performed over a three year period. Of necessity, to promote efficiency and uniformity, an evaluation protocol to be followed by the field research teams was developed. This methodology and related experience have been incorporated in a model plant evaluation protocol manual which is the subject of this paper. The manual presents a systematic approach to conducting a comprehensive performance evaluation of a municipal wastewater treatment plant. The ultimate objective of the evaluation is to identify and rank causes of poor plant performance. In the context of this evaluation procedure plant performance is measured by the consistency with which effluent quality meets the provisions of the NPDES permit.

The manual breaks down the evaluation into five major problem areas; design, performance monitoring, operation, maintenance and administration. In addition, the manual reviews the preparatory steps to be completed before the actual plant visit. Such preevaluation activities can be instrumental in assuring that data collection will be productive, efficient, and complete. A section on the preparation of the evaluation report is also included.

The protocol manual has been designed for use by an evaluation team that includes at least one individual with wastewater treatment engineering expertise and one individual with plant operation training and experience. In the case where a plant is small enough to be evaluated by one person, that individual should be a professional engineer who also holds operations certification. As noted above, this manual reviews the evaluation of treatment plant performance only insofar as effluent quality is concerned. Other aspects of performance, most notably energy utilization efficiency have not been addressed. Other references (4,5,6,7) have been, or are being, developed for that purpose. Furthermore, the manual does not provide guidance for in depth analysis of management issues or alternatives. Rather, we are concerned here with the "First Level" evaluation in which factors that directly impact effluent quality are investigated. The findings of the EPA biological plant performance surveys indicate that tangible performance improvements can be realized through implementation of programs on an operational level without necessarily making major management changes. This is not to minimize the significance of effective management to treatment plant performance. Over the long term good management practices will facilitate continuous optimization of plant performance and certainly improve the cost effectiveness of treatment. At least one reference currently addresses wastewater utility management in some detail (4). Finally, while the evaluation protocol manual reviewed in the following pages sets forth guidelines for structuring and conducting an evaluation, it is not to be considered all inclusive. Each treatment plant will present the evaluator with certain unique features and no single manual could cover all such contingencies. Other available references can and should be used to supplement the protocol manual. These include EPA published guidelines on NPDES compliance sampling, (8), facility staffing (9), methods for chemical analysis (10), and detailed evaluation of plant unit processes (11).

PRELIMINARY ACTIVITIES

In order to minimize time in the field and to maximize the quality of information gained, the necessary preliminary procedures should include:

1) Contacting cognizant regulatory officials to obtain all existing relative data.

2) Contacting responsible treatment authority or municipal officials to inform them of the proposed evaluation.

3) Contacting the treatment plant superintendent to inform him of the proposed evaluation, and to discuss the purpose and scope.

4) Estimation of time, manpower requirements, and materials needed to conduct the evaluation.

5) Formulation of field sampling and analytical program.

Some comments regarding these preevaluation tasks are presented in the following paragraphs.

REGULATORY AGENCY CONTACTS

The leader of the evaluation team should obtain all existing information on subject plant that may be on file with the EPA or state environmental control agency. Data to be acquired from the regional EPA office includes at least the STORET records for the subject facility and the EPA Form 7500-5 survey form, if one has been completed. The State Regulatory Agency should be assessed to obtain copies of the NPDES permit, monitoring records and any design related information that may be on file. These data are to be carefully reviewed to identify performance limiting problems that have been previously noted, and to observe past trends in effluent quality.

NOTIFICATION OF POTW AUTHORITY AND MUNICIPAL OFFICIALS

The chairman of the POTW owning authority and the head of the municipal department responsible for plant operation must be notified of the planned evaluation. The responsible official is usually the head of the department of public works or the municipal sanitation department. The NPDES permit can be checked to determine the responsible official. These officials should be notified in writing two weeks prior to the scheduled evaluation. Written notification should be followed with a telephone contact one week prior to the evaluation.

The written notification should indicate the reason for the evaluation; for example, to determine what factors are responsible for the failure of the treatment plant to meet its discharge permit. The scope of the evaluation should be briefly summarized, and the dates on which field work will be performed indicated. The responsible official should be asked to have his plant superintendent available throughout the field study period to respond to questions raised by the evaluation team and to provide copies of operating records. Furthermore, the responsible official is to be notified that the budgetary information for the most recent fiscal year is desired for review by the evaluation team, and that an individual should be designated as a contact for the evaluation team regarding budgetary and other administrative information. Names of the evaluation team personnel and the designated team leader should be included in the notification.

The administrative officials should be made aware of the positive aspect and tangible benefit that can result from the undertaking such as the identification of areas where O & M programs can be improved. Such improvements may involve minimal investment when compared to structural upgrading, but significant performance improvement may be achieved. The concept that should be communicated is that the evaluation is the first step in maximizing the return on the investment represented by the pollution control plant. If these ideas are clearly communicated, negative attitudes will be reduced and cooperation from the plant staff and administrators will facilitate the evaluation process.

NOTIFICATION OF THE POTW SUPERINTENDENT

Contact with the plant superintendent should not be made until the responsible authority or municipal official has discussed the scope and purpose of the evaluation with the plant superintendent. Then the team leader should call the superintendent to explain the nature of the evaluation to the superintendent, inform him of how much of his or his staff's time may be required, and answer his questions concerning the type and extent of information he will be asked to provide. The team leader should indicate the specific operating records and technical references he will inspect during the field investigation. The intent of contacting the plant superintendent is both to solicit his cooperation and to allow him some time to prepare so that information retrieval is expedited. No written contact need be made. Again, the concept that the evaluation team's findings may benefit his plant's performance is to be communicated to the superintendent.

CONTACTING CONSULTING ENGINEER OF RECORD

When the plant administration is notified, the name and address of the design engineering firm should be obtained. The administrator may refer the evaluation team leader to his consultant engineer to answer plant specific questions. In any case, the administrative official should be asked to give clearance to his engineer to release information regarding plant design to the evaluation team. The team leader should then directly contact the consultant and request to be given a copy of the basis of design, which may be returned to the consultant at the conclusion of the evaluation. Also, at this time, the scope and purpose of the evaluation should be discussed with the consultant. He should be asked for his suggestions concerning areas or facets of plant operation that should be specifically observed during the evaluation.

ESTIMATION OF EVALUATION TIME

Field time required for a comprehensive evaluation is a function of size of plant, complexity of treatment process, and the amount of cooperation provided by the plant operating staff. A minimum of three days in the field should be allowed for plants with design capacities of 11,355 cu m/d (3.0 mgd) or less and a minimum of five days field evaluation time should be allowed for larger plants. The cutoff point between three and five day field studies is somewhat arbitrary and based on average conditions. Judgment must be exercised in making adjustment in time allotments for plants where unusual or extenuating circumstances exist. It is better to overestimate the time required to conduct a comprehensive evaluation than plan for too tight a schedule. The slower pace will allow the evaluation team to better observe plant operations and to converse at some length with the operators. Such conversations can provide additional insight into problems which would otherwise be missed in the rush of a tight schedule. Also, the slower evaluation pace can result in an atmosphere in which the operating staff feels the evaluation team is providing some technical assistance to them. Under such circumstances, a good attitude and the cooperation of the plant staff increases the quality of the evaluation.

ESTIMATION OF REQUIRED MANPOWER

The provision of proper staffing involves two considerations. The number of individuals required to accomplish all tasks within the three to five day time frame must be determined. Just as important, however, is that the evaluation team include individuals with appropriate training and experience to gather all performance, design, operational, maintenance and administrative information, and to perform necessary sampling and field analysis. The number of individuals required to perform these tasks is a function of the size and complexity of the treatment plant. Since complexity of the treatment facility normally increases with design flow, manpower requirement can be related to plant size. Table 1 shows the recommended number of staff for an evaluation team as a function of plant design flow. This staffing guide should be viewed as a minimal allocation of manpower.

TABLE 1

GUIDE TO STAFFING REQUIREMENTS FOR COMPREHENSIVE EVALUATIONS

Plant Design Flow		No. of Investigators
cu m/d	mgd	
11,355	3	1
11,355-94,625	3-25	2
94,625-227,100	25-60	3
227,100	60	3 or more

Every evaluation team must include two categories of technical expertise; plant design and process operations. In the case of small plant evaluations where only one individual is involved, that individual must be an engineer who has had experience in treatment plant design or review of such designs, and has been involved in facets of plant operations. He should also be a registered professional engineer and hold state certification as an operator, in states where certification programs exist. Although an individual with this dual certification is not always available, experience and a working knowledge in both areas is absolutely necessary. In the case where an evaluation team is comprised of two or more individuals, at least one sanitary engineer and one certified operator should be included. Other individuals on the team may be technicians familiar with sampling, analysis, and field measurement techniques. These personnel would perform field data collection tasks under the supervision of one of the senior team members.

One of the senior team members should be designated as the evaluation team leader. The duties of the team leader include: (1) making all preliminary contacts, (2) collecting and coordinating review of previously available data, (3) overseeing scheduling, transportation, and lodging arrangements, (4) reviewing and approving of field sampling program, (5) coordinating field work, and (6) preparation of the evaluation report.

DETERMINATION OF REQUIRED EQUIPMENT AND MATERIALS

To enhance efficiency and organization of the field data collection effort, several forms have been developed for the protocol manual. As part of the preliminary activities, copies of these forms should be reviewed so that the evaluation team understands the data requirements and format before proceeding into the field. All available preevaluation information should be entered on the forms prior to the field study and confirmed during the field investigation.

The Field Analysis Requirement Form is a guide to be used to design the sampling and analysis program portion of the evaluation. It should be completed prior to the on-site work so that proper sample containers, reagents, and instruments can be obtained. However, a process flowsheet and some plant design information is needed to complete the form. If this information is not available, then sampling program decisions will necessarily be made in the field, in which case the team must be sure to bring sufficient sample containers and reagents to cover any contingency.

The following items are to be obtained, cleaned and calibrated prior to conducting the field study:

1. Sample Bottles - Approximately 1/2 liter capacity, sufficient number to sample plant influent, effluent, and interprocess streams at least daily during the 3-5 day survey. One hundred sample bottles will normally be sufficient.
2. Automatic Composite Samplers - To be used for sampling all wastewater flows including influent, primary effluent, secondary clarifier effluent, and final discharge.
3. Reagents for Sample Preservation - Sulfuric acid, nitric acid, mercuric chloride.
4. 50 Liter Cooler - For sample storage and transport.
5. Field pH Meter
6. Field D.O. Meter
7. Tape Measure - 30.5 m (100 ft.)
8. Bucket and Rope
9. Stop Watch
10. Dye Tablets
11. Protective clothing including boots and wet weather gear
12. Calculator
13. Clipboards

LABORATORY ANALYSES

The extent of laboratory analysis to be performed on collected samples depends on several factors. Of primary importance are the analyses for parameters required to quantify the process control indicators, which will vary with the treatment process flowsheet. Also, analyses for all discharge permit parameters should be performed on influent, effluent, and unit process flows so that removal of these pollutants may be profiled through the

TABLE 2. SUGGESTED SAMPLING AND ANALYSIS PROGRAM

Analyses	Sampling Points													
	Plant influent	Primary effluent	Aeration zone(s)*	Return activated sludge*	Trickling filter effluent	Secondary effluent	Tertiary effluent*	Plant effluent	Raw sludge	Primary digester sludge*	Secondary digester sludge*	Secondary digester supernatant*	Thickened sludge*	Dewatered sludge*
BOD_5 (total	x	x			x	x	x					x		
BOD_5 (soluble)	x											x		
Settleable solids	x							x						
Suspended solids (total)	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Suspended solids (volatile)			x	x					x	x	x	x		
Dissolved oxygen			x					x						
Phosphate*	x							x						
Ammonia nitrogen*	x							x						
Alkalinity										x				
pH	x		x					x		x				
Chlorine residual								x						
Fecal coliform								x						
Metals*	x													

---

* Where applicable

facility. Table 2 presents a general guideline indicating analyses to be performed on samples obtained from various points in the treatment process. Daily samples should be obtained at each indicated sampling point. Where possible, composite samples should be collected. Whether these should be time proportioned or flow proportioned, depends on the flow characteristics at the particular sampling point. Use of automatic samplers, wherever possible, is strongly recommended. This will reduce manpower requirements while improving sample integrity. Samples for solids analysis must be collected manually, but several samples per day should be combined into one composite. For all samples collected, careful judgment must be used in determining the actual point where a unit process will be sampled to assure that a timely representative sample is obtained.

Table 3 shows recommended sampling locations for the various plant unit processes. In the case of multiple parallel units, each unit should be individually sampled in order to isolate problems. There are many unusual or specialty processes that are not specifically covered in Table 3. In deciding where to sample such processes, the evaluator must exercise careful judgment. Every effort must be made to obtain the most representative sample in light of the purpose ofr sampling at the point in question. Additional references (8,11) will be useful in establishing sampling details.

Since no person is more familiar with access to the various plant units than the operator, Table 3 should be reviewed with him at the start of the field survey. The operator will be able to indicate where sampling ports, free discharges, or other appropriate sampling points can be found. If there is a serious problem with accessing a particular flow, and it is critical to the evaluation, alterations such as inserting a valve or tap in a line must be discussed with the supervisory operator. The long-term advantages of having complete sampling access for purposes of process control should be explained at that time. It may be necessary to postpone the evaluation for several days to allow any necessary modifications to be made.

TABLE 3

RECOMMENDED SAMPLING POINTS

Plant Influent	Wet well, after bar screen, comminutor and raw sewage pumps
Grit Removal	Near effluent weirs, approximately 2 feet beneath surface
Primary Clarifier	Free discharge into effluent launder (over weir)
Trickling Filter	Effluent junction box, beneath surface (or manhole if no junction box exists)

TABLE 3
(Continued)

Aeration Tank	Near center of tank, 2 feet beneath surface (D.O. should be run at several depths)
Sludge Return	Free discharge into aeration tank, return sludge distribution box, sampling valve on return pump
Secondary Clarifier	Free discharge at weir into effluent launder
Disinfection Unit	Near effluent weir (if chlorine residual is to be run, sample should be fixed)
Plant Effluent	At outfall discharge
Raw Sludge	Sampling port on sludge transfer line (or lines), free discharge into aerobic digester
Primary Digester	Tap on line between primary and secondary digester
Secondary Digester	Supernatant - at collection sump or port on recycle line, free fall discharge at plant headworks Sludge - free discharge to drying beds, influent line to thickener, influent line to holding tank for dewatering equipment
Thickener	Dewatering holding tank, influent line to holding tank
Polishing Pond	Near effluent weir or other discharge device
Polishing Filters	Tap on filter effluent line, discharge to chlorine contact tank

ESTIMATING THE COST OF AN EVALUATION

A budget for the comprehensive evaluation must be prepared during the planning stage. The variables that impact the cost of an evaluation include: duration of the survey, number of team members, extent of sampling and analysis program, and transportation, lodging and subsistence costs. A guide for estimating the funds to be budgeted for an evaluation is given in Table 4. Experience indicates the costs of comprehensive evaluations typically

TABLE 4

A Guide To Estimating The Cost Of A Comprehensive Evaluation

Cost Center	Variable No. 1		Variable No. 2		Variable No. 3	Constant	Subtotal
A. Pre-Evaluation Activities							
1. Make contacts and prepare correspondence	No. man-hours	x	Average payroll rate ($/hr)				
2. Review existing data	No. man-hours	x	Average payroll rate ($/hr)				
3. Prepare field sampling and analytical plan	No. man-hours	x	Average payroll rate ($/hr)				
4. Mobilization	No. man-hours	x	Average payroll rate ($/hr)				
Subtotal							
B. Field Investigations							
1. Labor	No. of investigators	x	Duration of survey	x	Average payroll rate ($/hr)	8-hours/ day	
2. Analytical	Cost per analysis (See Table 4)					No. of Samples for each analysis	
3. Lodging	No. of investigators	x	Duration of survey	x		Per diem ($/day)	
4. Transportation	(Round trip mileage + estimated at-site mileage			x		Vehicle rate ($/mile)	
5. Subsistance	No. of investigators	x	Duration of survey	x		Per diem ($/day)	
Subtotal							

TABLE 4 (Cont'd)

Cost Center	Variable No. 1		Variable No. 2	Variable No. 3	Constant	Subtotal
C. Report Preparation						
1. Data Reduction and analysis	No. man-hours	x	Average payroll rate ($/hr)			
2. Writing and editing	No. man-hours	x	Average payroll rate ($/hr)			
3. Typing and assembling	No. man-hours	x	Average payroll rate ($/hr)			
4. Printing and reproduction	No. of pages				Reproduction rate ($/page)	
Subtotal						
Total Evaluation Cost						

fall in the range of $3,000 to $8,000, including all field work and the preparation of an evaluation report.

MONITORING DATA COLLECTION

Three potential sources of monitoring data exist by which the performance of a treatment plant and its individual unit processes should be evaluated. First, there are the plant operating reports that document all analyses performed at the facility. The results of analyses performed on samples collected as part of the evaluation are the second source of monitoring data. The third source is the sampling and analysis information maintained by the regulatory agency in certain states.

PLANT MONITORING DATA

A member of the survey team should obtain copies of all monitoring data and reports maintained by the plant staff during the previous 12 months. Such information would include overall plant performance data such as flow records, influent and effluent BOD_5, suspended solids, phosphorus, nitrogen, and pH analyses. As a minimum, Such information should include results of all tests performed in accordance with the NPDES monitoring requirements, set forth in the plant's permit. Other available monitoring data maintained at the plant may include: primary effluent BOD_5 and suspended solids, MLSS MLVSS, and aeration basin dissolved oxygen (D.O.) and pH, and digester performance indicators, including alkalinity, volatile acids, temperature, and pH. Results of analyses on side streams such as return sludge, digester supernatant, thickener overflow, and dewatering filtrate should also be requested.

EVALUATION MONITORING DATA

One of the tasks performed by the evaluation team during a survey is the collection of samples for the purpose of monitoring process performance. Table 2 discussed earlier in this paper, indicates the inter-unit streams and process contents which should be sampled during the evaluation. The typical analyses to be performed on these samples have also been indicated. Sample volume requirements and preservation methods should be predetermined before arrival in the field.

REGULATORY AGENCY DATA

Certain state water pollution control agencies periodically conduct sampling and analysis studies at treatment plants within their jurisdiction as a check on performance. By contacting the respective state agencies, such data may be available for evaluation purposes or for confirming evaluation monitoring data.

Some general guidelines should be followed relative to samples collected in the field. Samples should be split and labeled aliquots preserved in accordance with intended analyses. Samples should be delivered as expeditiously as possible to the designated laboratory. Complete written instructions should be left with the laboratory supervisor specifying analytical parameters, suspected concentration ranges, reporting requirements for results, and deadlines for reported results. If the evaluation team does not have prior knowledge of a lab oratory, a visit to review items such as sample chain of custody, quality assurance, and record keeping procedures is suggested.

DESIGN ANALYSIS

An important part of the comprehensive evaluation is to evaluate the basis of design and to compare the plant facilities in place with the basis of design. The objectives of this portion of the comprehensive evaluation are to (1) discern any design factors which may limit the ability of the plant to meet its permit conditions, (2) determine the limitations on operations imposed by design, and (3) identify minor design deficiencies that may be easily and inexpensively corrected. This analysis will include examination of process design parameters, such as detention times, hydraulic and organic loadings, recirculation rates, and sludge age. Also, a visual comparison of plans and specifications to existing equipment and layout must be made to determine if changes have been made either at the time of construction or thereafter. The adverse impact of some design errors or omissions, such as undersized unit processes, is easily perceived. However, the evaluation team must also establish the extent to which more subtle design problems adversely impact the performance of the treatment plant. Examples of such problems could be inadequate sludge return or wasting capacity, or poor control over recycle flows. Inadequate process flexibility is another potential design problem that may not be readily apparent on initial review of the basis of design.

General design information can be obtained from several sources. These include: the preliminary engineering report or 201 Facilities Plan prepared for the plant, the plant basis of design, the O&M manual, as-built drawings retained by owner, design drawings retained by the consultant engineer, and permit applications on file with the state regulatory agency. In addition to all unit process design information, design wastewater characteristics and flows must also be determined. As a minimum the general background information that must be obtained to evaluate the treatment plant design includes:

-- Average design flow
-- Peak design flow (rate)
-- Design BOD_5 and suspended solids loadings
-- Design service population
-- Design year
-- Age of existing facility
-- Present average flow
— Present peak flow (rate)
-- Present BOD_5 and suspended solids loadings
-- Present service population
-- Volume of industrial wastewater
-- Character of industrial wastewater (BOD_5, suspended solids, heavy metals, toxics, etc.)
-- Volume of infiltration/inflow

In addition, review of recent operating records, or regulatory agency inspection records, must be conducted to obtain information on current wastewater flows and characteristics. Records of any infiltration/inflow analyses that have been performed are available from the plant owner or the consulting engineer.

The major portion of the design evaluation phase is devoted to the analysis of individual unit process designs. This analysis consists of determination of process design parameters and loadings, comparison of these parameters with good engineering practice, and comparison of design parameters with values realized in the process under actual operating conditions. Thorough evaluation of unit process design will provide the necessary information to establish the existence and degree of the following potential plant performance limiting conditions:

1. Poor process design which subverts the ability of a process to meet design intent. For example: excessive solids loading on a secondary clarifier, inadequate detention time in an aeration tank, etc.

2. Construction or installation which does not conform to design. An example would be clarifier weirs installed out of level, causing short circuiting in the unit.

3. Inadequate process flexibility. This situation interferes with the operator's ability to adjust the process to variations in wastewater conditions. An example of this would be an activated sludge return line for which flow cannot be adjusted.

4. Poor process selection. An example would be the use of the contact stabilization mode of the activated sludge process to treat wastewater which is highly variable in organic strength.

5. Incompatibility of unit process with the constituent removal requirements. An example of this would be the use of a secondary clarifier to achieve effluent suspended solids concentrations of less than 20 mg/l.

All unit process design evaluations must be conducted with the above five potential problem areas being carefully considered.

It can be expected that some of the following unit processes must be evaluated at any biological treatment facility:

Raw sewage pumping
Screening
Shredding
Grit removal
Flow measurement
Primary sedimentation
Trickling filters
Aeration (Activated Sludge)

Rotating biological contactors (RBC)
Secondary sedimentation
Disinfection
Filtration
Microscreening
Carbon adsorption
Land application (wastewater)
Thermal sludge conditioning
Sludge thickening
Anaerobic digestion
Aerobic digestion
Sludge dewatering
Land application (sludges)

Design and current loading parameters must be obtained for each of these unit processes. A form is provided in the protocol manual to facilitate collecting this data. Though the collection of design data is a somewhat routine undertaking, the evaluation team must be continually aware that the data must be complete to definitely determine whether unit process design is in any way placing limitations on the plant's performance.

The protocol manual sets forth guidelines for the collection and manipulation of data for each of the above listed unit processes, although brevity precludes such detail in this paper. Design parameters to be investigated and raw data needed to calculate them are specified for each unit process. Various references such as "WPCF Manual of Practice No. 8" (12), the EPA Technology Transfer Series, and tests such as that edited by Metcalf and Eddy (13), can be used to establish ranges for design parameters considered representative of good engineering practice.

In conducting the design analysis the evaluation team must be aware that all potential design problems are not necessarily evident upon an analysis of unit process loadings. Factors such as process flexibility, accessibility of sampling points for process control, capability to divert and balance flows, and calibration requirements for process control instruments should be evaluated.

OPERATIONAL INVESTIGATIONS

The evaluation of operational capabilities and limitations comprises an extremely important segment of a comprehensive evaluation of a treatment facility. This area historically has not been given adequate consideration in plant evaluations. Operational factors affecting plant performance range from qualitative factors such as the personal characteristics and traits of operators (e.g., process knowledge and general aptitude), to more quantitative physical constraints placed on the staff, such as deficiencies in laboratory equipment or a lack of reference materials. The evaluation team must be objective but diplomatic during all of its fact-finding activities, but this is especially true in relation to operations. The operators may be very sensitive to question in this area, because they may interpret the evaluator's questions as an attempt to assess their job performance. To some degree, operator job performance must be assessed in this section of the comprehensive evaluation.

In the evaluation protocol, plant operational practices are divided into four major categories: operating personnel, plant monitoring, process control, and operations references. The information to be obtained for each category is discussed. Also, for comparison purposes, acceptable baseline capabilities are given wherever possible which will assist the evaluator in determining the adequacy or acceptability of plant operational procedures and resources. A form for the purpose of summarizing operational data is included in the protocol manual.

The best engineered plant would not perform to its potential without the management provided by a capable operator. Conversely, many poorly designed plants can and do perform satisfactorily with respect to effluent criteria due to conscientious and capable operators. Through discussions with the plant superintendent the evaluation team must establish the abilities and limitations of the operating staff. At small plants this may involve indepth discussions with only one operator. At larger facilities, the investigations should be directed toward the chief operator for each shift or the individuals in charge of overall operations, those in charge of specific process operations (i.e., digester control operator), and those responsible for laboratory functions.

The evaluator should determine the level of education of each of the responsible operating personnel. For individuals in supervisory positions and in situations where there is only one operator the equivalent of a high school graduate would be considered baseline. The evaluation team must assess the level of knowledge that the plant operators have regarding wastewater treatment. The aptitude of the operating personnel in this regard must be assessed through question-and-answer sessions in which treatment theory and process control techniques are discussed. Careful analysis of the operators responses is the best way to determine his ability to comprehend and apply the concepts of wastewater treatment. Specific questions to be asked depend on the type and complexity of treatment process involved. For example, in the case of an activated sludge plant the operator might be asked if he has ever encountered a bulking problem and, if so, what action he took in response. He might further be asked if he feels his process can be controlled by F/M or mean cell residence time techniques and how this might be accomplished. The operator of a trickling filter plant might be asked about his plant's recirculation control capabilities. Questions concerning sludge handling and disposal, and laboratory techniques should also be posed.

Operator attitude has an important bearing on the overall performance of a plant. A good attitude toward operating the plant is an indication that the personnel are at least expending the effort to produce a high quality effluent. Evaluation of operator attitude is necessarily subjective. Often a poor attitude is evidenced by excessive complaining about working conditions; an antagonistic reaction to the evaluation; placing all culpability for performance problems on the engineer, plant administration, or regulatory entities; an inability to get along with others; high rate of absenteeism; or (of most importance) indifference toward the problems at the plant. This last manifestation of poor attitude is usually accompanied by poor records keeping, poor condition of equipment, and inadequate laboratory testing. It is recognized that in many instances operators complaints are justified by the circumstances. The evaluator must judge the degree to which the operator is offering constructive criticism, and conversely, the degree to which negativism and attitude problems prevail.

Monitoring activities conducted at a treatment facility by the operating personnel are a good indication of the emphasis placed on operations, and the operator's understanding of process control. The evaluation team is responsible for making value judgment relative to several types of monitoring activities. Firstly, the sampling program followed at a treatment plant must be compared with recommended or required procedures. Performance sampling should conform with permit requirements. Such requirements may include composite sampling. The frequency of sampling may also be specified. If samples are going to be held for any period longer than a few hours before beginning the laboratory analyses, preservation techniques should be routinely employed. Laboratory procedure should be evaluated by direct observation of technicians, or at least by means of detailed interview of technicians regarding their analytical methods and laboratory procedures. A form has been provided in the protocol manual for performing the laboratory evaluation.

Process testing should be evaluated in a manner similar to performance testing. Although these tests are not required by permit, effective process control of certain unit processes, such as the activated sludge system or the anaerobic digester, requires such tests be conducted in order that appropriate control adjustments may be made. Unlike the performance testing case, process testing scope and frequency will not be set forth in regulatory permits. Therefore, the evaluator must use judgment and references in setting a framework of acceptable process testing at a given plant. Table 5 presents a guide for evaluating the acceptability of process control testing for various processes and interprocess streams, for plants in the small, medium, and large design categories. The table may be used as a general guide, but specific conditions at each plant should be taken into consideration when applying the table in the field.

Maintaining adequate records of plant monitoring is an important aspect of operations. Records should include copies of NPDES monitoring reports dating back at least two years and complete records of all process monitoring for the current and previous year. As a minimum, annual summary sheets of all performance and process monitoring should be filed at the plant for all previous years. Neatness and organization of monitoring records should be assessed.

An effective process control program is essential if a biological treatment plant's performance is to be optimized. This is especially true in the case of activated sludge systems. However, process control is not something that will be easily quantified by the evaluation team. In most cases, the evaluators will have to rely on discussions with the plant superintendent and/or operators to supplement available records and observations.

Table 5

Guide for Evaluationg Process Testing

	BOD$_5$	Suspended Solids	Volatile Suspended Solids	D.O.	pH	Alkalinity	Volatile Acids
PRIMARY EFFLUENT							
Less than 1 mgd	1/wk	1/wk	-	-	Daily	-	-
1 to 5 mgd	2/wk	2/wk	-	-	Daily	-	-
Greater than 5 mgd	2/wk	2/wk	-	-	Daily	-	-
TRICKLING FILTER EFFLUENT							
Less than 1 mgd	1/wk	1/wk	-	Daily	-	-	-
1 to 5 mgd	2/wk	2/wk	-	Daily	-	-	-
Greater than 5 mgd	2/wk	2/wk	-	Daily	-	-	-
MIXED LIQUOR							
Less than 1 mgd	-	2/wk	1/wk	Daily	Daily	-	-
1 to 5 mgd	-	4/wk	2/wk	3/day	Daily	-	-
Greater than 5 mgd	-	Daily	4/wk	3/day	Daily	-	-
RETURN SLUDGE							
Less than 1 mgd	-	1/wk	1/wk	-	-	-	-
1 to 5 mgd	-	2/wk	1/wk	-	-	-	-
Greater than 5 mgd	-	4/wk	2/wk	-	-	-	-
THICKENED SLUDGE							
Less than 1 mgd	-	1/wk	1/wk	-	-	-	-
1 to 5 mgd	-	2/wk	2/wk	-	-	-	-
Greater than 5 mgd	-	2/wk	2/wk	-	-	-	-
PRIMARY DIGESTER							
Less than 1 mgd	-	-	1/wk	-	2/wk	1/wk	1/wk
1 to 5 mgd	-	-	2/wk	-	Daily	2/wk	2/wk
Greater than 5 mgd	-	-	2/wk	-	Daily	2/wk	2/wk
DIGESTED SLUDGE (Aerobic and Anaerobic)							
Less than 1 mgd	-	1/mo	1/mo	-	-	-	-
1 to 5 mgd	-	1/wk	1/wk	-	-	-	-
Greater than 5 mgd	-	2/wk	2/wk	-	-	-	-
DEWATERED SLUDGE							
Less than 1 mgd	-	1/mo	1/mo	-	-	-	-
1 to 5 mgd	-	1/wk	1/wk	-	-	-	-
Greater than 5 mgd	-	2/wk	2/wk	-	-	-	-
RETURN STREAMS (Thickener overflow, secondary digester supernatant, filtrate)							
Less than 1 mgd	1/mo	1/mo	1/mo	-	-	-	-
1 to 5 mgd	1/wk	1/wk	1/wk	-	-	-	-
Greater than 5 mgd	2/wk	2/wk	2/wk	-	-	-	-

The evaluation team must determine how knowledgeable the operator is with respect to process control methods. Are the typical process control parameters, such as food to microorganism ratio (F/M) and mean-cell residence time (MCRT), familiar to the operator? Does the operator understand how to calculate these parameters and does he know what reasonable values are? Is he aware of the process control monitoring (i.e., influent BOD_5, MLSS, volume of sludge wasted, etc.) which must be performed to determine such control parameters? The evaluation team must determine if a rational process control stategy exists and how thoroughly that strategy is implemented.

Previous plant performance surveys have shown that at some plants, the operator performs the recommended process tests, but makes no effective use of the information. For example, MLSS levels may be monitored daily, although no attempt is ever made to adjust sludge wasting routines in order to maintain an optimum MLSS concentration. Through discussions with the operator and review of plant records the evaluation team must determine whether the process monitoring data is being used to control the facility's performance or simply being compiled.

Good technical references are a significant asset to the operator with respect to efficient plant operation. The operations manual prepared specifically for the plant is the most important reference. Other reference materials relating to operations include manufacturer's literature, publications by professional organizations such as the Water Pollution Control Federation, and EPA documents.

The evaluation team should judge the adequacy of the operations manual at each plant. A comprehensive operations manual will address all aspects of the plant including laboratory functions, testing, process control, and safety. Start-up and shutdown procedures for all equipment should be presented in a stepwise fashion. The control center or panel should be described in detail with particular emphasis on the features of automatic control systems. The manual should include detailed schematics of the plant piping that show all pumps, valves, and similar control devices. Troubleshooting procedures should be described in detail. The manual should contain a detailed process control procedure. This procedure should include all process testing requirements as well as centerlines and ranges for key process control parameters. The evaluation team should discuss the adequacy and use of the manual with the operator.

Operational literature is frequently supplied to the treatment plant by equipment manufacturers. These references provide operators with specific information on equipment and unit processes that is intended to supplement the comprehensive operations manual. The evaluation team should first assess the availability and extent of such information at the plant itself. The evaluators should also determine whether the manufacturer's information fills any voids in the comprehensive manual.

Operations publications from professional organizations include Manuals of Practice (MOP) prepared by the WPCF and various state association handbooks. Such publications provide the operator with additional insight regarding items such as process control techniques and troubleshooting. Those reference materials are particularly important if the plant lacks a detailed comprehensive manual. The evaluation team should note the presence or absence of such publications. Do the operators find these references helpful? Are these publications frequently consulted? The contents and scope of these references should be discussed with the operator. Another reference source for treatment plant operations is made available by EPA under the Technology Transfer Series. The evaluation team should note the availability of these references at the plant site, and should inquire as to their value to the plant staff. Do plant operators find these publications understandable? Have the manuals been used or merely stored on site.

In summary, thorough evaluation of operational factors is critical to the comprehensive evaluation. Successful investigation of this area requires in-depth conversations with the operating staff as well as careful analysis of operating records and observed process control and testing techniques. The evaluation team should be prepared to devote at least 50 percent of its field time to this effort.

MAINTENANCE INVESTIGATIONS

Maintenance of the treatment plant is a primary responsibility of the staff. Maintenance duties typically range from performing routine maintenance functions, such as lubrication, to on-site major repair of equipment. The plant maintenance program and its degree of success are a function of design and construction methods, as well as staff capabilities. Various aspects of plant maintenance must be examined by the evaluation team and are discussed in the protocol manual.

The evaluators are directed to note all process units or equipment which are inoperable at the time of the evaluation. Through discussions with the operator, the team should determine the length of downtime for each unit, the performance and maintenance history of the unit, and estimate the level of effort that would be required to put the unit back in operation. The evaluation team must assess the impact of out of service units on plant reliability and performance. The evaluation team should also document which major plant processes are provided with multiple units to provide backup capabilities or partial treatment during maintenance periods. The evaluators must question, in depth, the plant operators and maintenance staff with respect to which processes or equipment are the major problems from the maintenance viewpoint and where they feel additional preventive procedures or spare parts inventory are warranted.

Any units in operation but in need of repair should be noted. Symptoms of such needed repairs are noisy bearings in motors, seal and gland water leaking from pumps, oil leaking from mechanical parts (other than minor drippage), and excessive digester fuel consumption for heating purposes. The evaluation team should reveiw with the plant maintenance personnel each of the units determined to be in need of repair or servicing; noting their comments regarding the reasons for such conditions, any proposed repair schedules, and any long-range programs for eliminating such conditions in the future.

Scheduling of routine or preventive maintenance is to be assessed. Examples of such maintenance include: lubrication, periodic draining and cleaning of tanks, repairing sludge scraping and skimming mechanisms, repacking pumps, replacing bearings, cleaning diffusers on air headers and nozzles on trickling filter distributors, and cleaning flow measuring devices and monitoring equipment. Is such maintenance performed on schedule or only when time permits? Records for each piece of equipment requiring maintenance should include the date and cost of repairs, time to repair, manpower expenditures, materials, and outside contractor costs. Generally, the evaluation team should determine whether the emphasis at the plant is placed on preventive or corrective maintenance. The existing spare parts inventory and procurement procedures should be carefully assessed.

To effectively deal with emergency situations the plant must maintain certain baseline capabilities or provisions. An alternate power source (i.e., gasoline- or diesel-powered generators, or a second power service line from a separate substation) should be provided. Audible alarms should alert failures of major equipment items, such as pumps, chemical feeders, mixers, or aerators. Also, portable pumps should be readily available in case of flooding. The manpower resources available to the plant in times of emergency must be assessed. Such manpower includes permanent staff and personnel from other departments or private contractors that may be brought in on short notice. Contingency plants and provisions for emergency communications should be reviewed.

In short, the evaluation of plant maintenance practices involves visual observations to assess housekeeping practices and equipment upkeep, careful review of maintenance schedules and records, review of spare parts availability, and an evaluation of the maintenance references available to the operator. The protocol manual includes a maintenance checklist to be completed by the evaluation team.

ADMINISTRATION

A wastewater treatement facility must obviously be operated within the constraints of administrative policy and provisions. In some cases blatant administrative shortcomings such as severe understaffing or under budgeting may directly inhibit treatment plant performance. In other cases, however, administrative shortcomings of a more subtle nature may indirectly impact effluent quality. The latter condition may be difficult to discern by an evaluation team. Indeed a thorough management-administrative evaluation could constitute a separate study of greater scope than the entire evaluation covered by the manual discussed in this paper. As indicated earlier, in depth analysis of wastewater utility management is the subject of other references. However, the protocol manual does present guidelines for a very general assessment of administration which is designed to expose major plant performance limiting problems. Four key aspects of plant administration are reviewed: plant staffing, budeting, staff training, and use of outside technical experts.

It is unrealistic to expect any treatment facility to produce an effluent which consistently meets permit requirements and design performance standards if the plant does not have a sufficient number of employees to provide needed operation and maintenance. In an evaluation, plant staff responsibilities are grouped according to the following classifications: management, operations, maintenance, laboratory, and clerical. Unfortunately, labor breakdown at treatment facilities is not always in accordance with these classifications. For example, at small plants, a single employee may be responsible for all five labor categories. Even at large plants, an individual may be called an operator, although his duties include laboratory or clerical work. If an employee's time is divided between two or more labor categories, an estimate of the fraction of total time devoted to each category should be made. This should be accomplished by discussing the responsibilities and duties of each plant employee with the superintendent, and with his help, establishing the percentage of working time which each employee devotes to each of the five categories. The evaluation team should also note the number and specific days of the week that the plant is attended, the number of shifts staffed and the duty hours, and the types of personnel staffing and the categories of activities undertaken during the various shifts.

After the staffing information is gathered, the evaluation team must assess the adequacy of: 1) the number of plant employees, 2) the distribution of manpower among the five labor categories, and 3) shift coverage. Where deficiencies are noted, the team should discuss with the superintendent the extent to which these deficiencies have affected the performance of the plant. Also, the evaluation team must determine how successfully the present plant staff could respond to any noted deficiencies, and assess the need for additional personnel. For example, if a deficiency is evident in the area of process control, the evaluator must determine (in this example) whether the currently employed personnel can handle the additional responsibilities to correct the deficiency.

One reference for estimating baseline staffing requirements is the EPA technical report entitled, "Estimating Staffing for Municipal Wastewater Treatment Facilities". (9) Because all plant specific contingencies could not possibly be covered, the staffing estimates prepared according to guidelines given in this document are not to be considered absolute requirements. However, this reference provides the mechanics for making a first order estimate of staffing heads for a given size and type of facility and should be used as such.

Budgeted funds for operation and maintenance are often cited as being responsible for deficiencies in performance. However, many facilities are operated effectively on tight budgets and are able to meet performance standards. The evaluator must discern when funding is used as an excuse for poor performance when it is not the true cause. Also, the team must determine not only the adequacy of the operating budget, but the impact that budget has on performance. The evaluation team must renew and analyze plant budget data. The protocol manual includes a form for organizing such data.

For reference purposes, the publication, "Analysis of Operation & Maintenance Costs for Municipal Wastewater Treatment Systems", (14) can be used.

It presents the results of comprehensive cost surveys for plants of various types, sizes, and geographical locations and can be used to compare operating costs at a particular facility with the costs at similar facilities within the same geographic area. The drawback to using the document to develop standards of comparison is that it is not known how many plants included in the data base may have been inadequately funded.

If the adequacy of budgeting is suspect or the inadequacy is documented, the evaluation team should identify the needed improvements in budget amounts and categoreies. Areas where budget shortfalls are perceived should be scrutinized to determine how plant performance is being specifically impacted, for example, low salaries may be responsible for operation being left to incapable or poorly trained individuals.

Level of staff training is considered to be an administrative matter, because entry level requirements as well as the opportunity to participate in training courses are determined by those individuals with administrative responsibility for the plant. Discussions should be held with the plant operators to determine the extent of training received. Completion of formal courses should be noted. Attendance at conferences and seminars should be assessed. The team should determine the number and level of certified operators on the plant staff. State certification is an indication of basic background knowledge of waste treatment fundamentals.

In some instances, plants have instituted relatively sophisticated on-the-job training programs, in which the more experienced, better trained, senior operators convey their knowledge to new or inexperienced employees through formal hands-on training seminars or programs. Also, in many cases, consultants are retained to provide training during start-up of new or upgraded facilities. Whenever programs such as these are encountered, the evaluators should determine their relative effectiveness.

The extent to which consultants or outside technical experts are employed is also an administrative decision. The evaluation team should discuss with the plant superintendent or appropriate administrative official the extent of their use of consultants or other technical experts. Is there an on-going service agreement with a consultant or is technical assistance only called upon when problems develop? The evaluation team must also assess the effectiveness of technical assistance that has been employed.

Finally, evaluation of plant administration involves some subjective judgment regarding attitudes and policies. In some cases municipal officials have considered treatment plant needs a low priority item relative to other municipal services. Such attitudes will be reflected in plant condition and performance. The evaluation team can only discover problem attitudes and/or policies through careful interview of officials and plant staff.

REPORT PREPARTAION

The plant evaluation report must summarize data and present conclusions resulting from the on-site observations and analyses and related computations. In addition, the report should make specific recommendations for improving the plants performance within the limitations of operational, maintenance, administrative or minor structural changes. The effectiveness of the evaluation as a foundation for preparation of the CCP will be a function of the quality of the report.

Although rigid report guidelines cannot be followed in all situations, certain components are essential to the evaluation report. For this reason the protocol manual presents a standardized report format indicating the areas that should be covered in the report. The suggested report structure is as follows:

Section 1. Summary - This section of the report briefly summarizes the performance of the facility and identifies the major problems or deficiencies noted during the survey.

Section 2. Description of Plant - This section describes the plant's location and presents a general description of the plant. A process flow schematic should be included. Permit criteria should be recorded. Additional information to be presented includes: age of facility, date of most recent upgrading, and point of discharge.

Section 3. Design Evaluation - This section presents a unit-by-unit analysis of the treatment facility, addressing all major unit processes. The process design evaluation should include the completed "Design Evaluation Summary" form. A discussion of design errors, deficiencies, and overloads should be included, along with their impact on plant and process performance.

Section 4. Performance Evaluation - This section summarizes the plant's actual performance as it relates to both design intent and optimum capabilities. Performance should also be described statistically in terms of its compliance with NPDES limitations over the 12-month period. Annual average flows, influent and effluent pollutant concentrations, pollutant loadings, and percent removals should be documented.

Section 5. Operations Evaluation - This section summarizes the findings based on investigations of plant operational practices. The completed forms, "Laboratory Testing Capability and Performance" and "Summary of Operations Performance Indicators" should be included in this section. All observations with respect to operating practices and procedures should be reported. This section should identify, in detail, potential operationally oriented causes of performance problems. Where program improvements are necessary, such needs should be treated.

Section 6. Maintenance Evaluation - This section summarizes the results of maintenance investigations. The completed form, "Summary of Maintenance Performance Indicators" should be included. The section should include observations made concerning maintenance programs. Areas of plant maintenance that can be cited as potential causes of performance problems should be identified. Additional maintenance needs should be noted.

Section 7. Administration Evaluation - The completed forms, "Wastewater Treatment Facility Annual Operating Budget" and "Summary of Administrative Practices and Policies" should be included in this section. Administrative shortcomings should be reported, as well as their apparent impact on other plant areas. Needed improvements in plant administrative procedures are to be noted.

Section 8. Plant Evaluation Summary - The "Plant Evaluation Summary" should be presented, including a brief discussion on how to interpret the information contained in the summary. Instructions for completing this document are included in the protocol manual.

Section 9. Conclusions and Recommendations - This section presents all relevant conclusions regarding plant design, performance, operation, maintenance, and administrative factors adversely affecting plant performance. Causes of performance problems should be summarized. Actions to correct shortcomings should be classified as either:

1. Improvements needed to correct deficiencies that have been directly correlated with performance problems (first priority), or
2. Improvements needed to correct deficiencies, although performance problems cannot be directly correlated with such deficiencies (second priority).

Each corrective action should also be classified with respect to being either:

1. A non-capital expenditure improvement, which is any action not involving the construction or modification of major physical facilities (first priority), or
2. a capital expenditure improvement, which is any action involving the construction or extensive modification of major physical facilities (second priority).

Wherever possible, the costs of implementing the corrective actions should be estimated. Specific recommendations should be presented. With few exceptions, recommendations must be limited to those corrective actions classified as "first priority" in both of the categories above.

Exceptions would include any improvement that would require no (or minimal) cost. This section should also include a statement of the best effluent quality believed by the evaluator to be achievable if all non-capital intensive recommendations were to be implemented.

REFERENCES

1. Gilbert, W.G., Relation of Operation and Maintenance to Treatment Plant Efficiency, Journal Water Pollution Control Federation, 48(7): 1822-1833, 1976.

2. Gray, A.C., Roberts, H.D., and Paul, P.E., "Evaluation and Documentation of the Effects of Operation and Maintenance Practices on the Performance of Selected Biological Treatment Plants", Final Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.

3. Hegg, B.A., Rakness, K.L., and Schultz, J.R., "Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance", EPA-600/2-79-034, NTIS No. PB-300331, U.S. Environmental Protection Agency, Cincinnati, Ohio (1979).

4. Wastewater Utility Management Manual, prepared by Government Finance Research Center, July, 1981.

5. Energy Conservation in the Design and Operation of Wastewater Treatment Facilities, Water Pollution Control Federation, 1981.

6. Energy Conservation in Municipal Wastewater Treatment, EPA-430/9-77-011, U.S. Environmental Protection Agency, Washington, D.C., March 1978.

7. Energy Conservation at Wastewater Treatment Plants, Special Publication, Technical Practice Committee, WPCF.

8. NPDES Compliance Sampling Inspection Manual, NTIS No. PB-81-153211, U.S. Environmental Protection Agency, Washington, D.C.

9. Estimating Staffing for Municipal Wastewater Treatment Facilities, MO-1, U.S. Environmental Protection Agency, Washington, D.C., 1973.

10. Methods for the Chemical Analysis of Water and Wastes, EPA-600/4-79-020, U.S. Environmental Protection Agency, Cincinnati, Ohio 1979.

11. Hinrichs, D.J., "Inspectors Guide for Evaluation of Municipal Wastewater Treatment Plants", U.S. Environmental Protection Agency, Contract No. 68-014727, 1979.

12. Miorin, A.F., ed., Wastewater Treatment Plant Design, WPCF Manual of Practice No. 8, 1977, 560 pp.

13. Metcalf and Eddy, Inc., Wastewater Engineering, McGraw Hill Book Company, New York, N.Y., 1972, 734 pp.

14. Analysis of Operations and Maintenance Costs for Municipal Wastewater Treatment Systems, EPA-430/9-77-015, NTIS No. PB-283471, U.S. Environmental Protection Agency, Washington, D.C., February 1978.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agnecy's peer and administrative review policies and approved for presentation and publication."

PAPER NO. 3

OPERATION AND MAINTENANCE CONSIDERATIONS OF LAND TREATMENT FACILITIES

by

Kimm Perlin
Project Engineer

Roy F. Weston, Inc., Designers-Consultants
West Chester, Pennsylvania 19380

OPERATION AND MAINTENANCE CONSIDERATIONS OF LAND TREATMENT FACILITIES

Kimm Perlin, Project Engineer
WESTON, Designers-Consultants, West Chester, PA

INTRODUCTION

Land treatment of municipal wastewater has been practiced since 1840. The use of land to treat domestic wastewater has received major impetus recently with the passage of the 1972 Amendments (PL 92-500) and the 1977 Amendments (PL 95-217) to the Federal Water Pollution Control Act. The 1977 Amendments, the Clean Water Act, provide certain incentives for funding land treatment systems through the U.S. Environmental Protection Agency (EPA) Construction Grants Program.

Previous EPA research has focused on two aspects of the land treatment of wastewater: The long-term environmental effects of land treatment, and the design considerations for land treatment systems. None of this research adequately addresses the issues of operation and maintenance of land treatment systems. The purpose of the study described in this report was to provide information on operation and maintenance, staffing, and costs. Also, the study was intended to describe problems currently being experienced at land treatment sites due to operator and/or design limitations. The study was divided into two phases.

In the first phase, a project team visited various sites using land treatment systems to collect information on practices currently in use. The information was collected on several general areas. One area was facility staffing. The data collected included numbers and functions of the people engaged in operating and maintaining the land treatment system and other treatment systems at the site.

Other types of data collected during the site visits were in the areas of process control and operational information. Information collected included the operational strategy used by the operator to decide where, when, and how much wastewater should be applied. A third area in which data were gathered during the site visits was operation and maintenance costs. Data on operation and maintenance costs of the land treatment system were collected, and if possible, divided into salaries, energy, chemicals, materials, and other well-defined categories.

During the site visits, data were also collected on factors that hinder the operation and maintenance of a land treatment facility. The adequacy of the groundwater monitoring practices was also assessed during the site visits. Neighbors whose property was adjacent to or in the vicinity of the land treatment system were interviewed to determine the impact of the land treatment system on private individuals.

The second phase of the study was the development of definitive recommendations for procedures to improve the operation and maintenance of land treatment systems.

The recommendations were developed from two different viewpoints. The first viewpoint involved the type of land treatment system. Therefore, all three major types of land treatment systems were visited: slow-rate (irrigation), rapid infiltration (infiltration-percolation), and overland flow systems. The second viewpoint involved the degree of preapplication treatment associated with the facility. Therefore, facilities where primary-, secondary-, and tertiary-treated wastewater is applied were visited. In addition, facilities with different types of treatment, e.g., trickling filter versus activated sludge secondary treatment, were visited. The potential effects of climatic conditions were also included.

The overall goal of the research project was to make specific recommendations to improve and optimize the operation and maintenance of land treatment systems.

BACKGROUND

The evaluation of a land treatment system is different from the evaluation of typical wastewater treatment process in that there is little in the way of direct evidence as to the effectiveness of the land treatment system. Therefore, determination of the adequacy of a land treatment system must rely on circumstantial evidence.

The following data are needed to assess the adequacy of a land treatment system:

- Design loadings as compared to typical design limitations.
- Compliance/noncompliance with applicable state and Federal regulations/guidelines.
- Visual observations (aesthetics, plant health, soil condition, etc.).

- Maintenance practices.

- Operational practices.

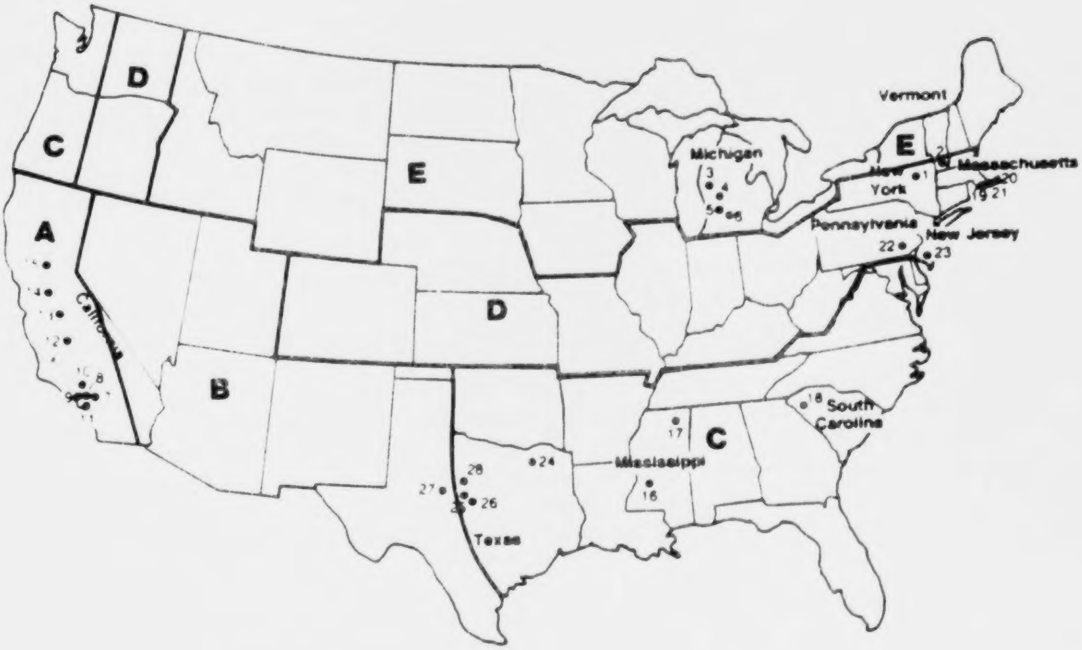
It is only through consideration of such parameters that the performance of a land treatment system can be adequately assessed. In other words, a direct standard, such as effluent quality, by which the system can be gauged is not available. Therefore, adherence to reliable design, operation, and maintenance practices are used to determine the presumptive adequacy of a system.

The sites visited were selected based on a variety of factors, including degree and type of preapplication treatment, climatic conditions, and type of land application system. Using these guidelines, the selected sites have been plotted geographically, as shown in Figure 1. The sites are clustered around California, Michigan, and Texas since this is representative of the geographical distribution of land treatment systems in the United States. Figure 1 also presents the five different climatic zones in the United States, as presented by Sullivan, et al (1973) (1). At least one site was visited in each of the climatic zones.

During the site visits, a trip questionnaire/checklist was completed for each location. The types of data collected are summarized in Table 1. The majority of information learned during the site visits is believed to be factual. Certain questions, however, required estimation on the part of the treatment plant personnel in order to supply the required information. In cases where the personnel were unable to provide the information requested, the data were estimated, if possible, by the interviewers.

Of the questions posed, the budgetary questions proved to be the most difficult to answer. One question involved the budget information for the operation and maintenance of the facility. For the majority of the facilities visited (26 out of 28), the budget information obtained applied to the entire treatment facility as the funds spent on land application were not separated from those for preapplication treatment. This necessitated estimation to ascertain how much money was spent in each area. Furthermore, at some of the smaller facilities, collection and treatment costs were lumped together and had to be separated.

The budgetary problem is further complicated by the fact that it is sometimes difficult to decide if equipment is part of the preapplication treatment or the land application treatment


D
C
A
B
E
D
E
C
Michigan
Vermont
New York
Massachusetts
Pennsylvania
New Jersey
South Carolina
Mississippi
Texas
California
1
2
3
4
5
6
8
9
10
11
12
16
17
18
19
20
21
22
23
24
26
27
28

A - Mediterranean Climate --
Dry Summer, Mild, Wet Winter

B - Arid Climate -- Hot, Dry

C - Humid Subtropical -- Mild Winter,
Hot, Wet Summer (Washington, Oregon
Area Mild, Moist Summer)

D - Humid Continental -- Short
Winter, Hot Summer

E - Humid Continental -- Long
Winter, Warm Summer

(Adapted from Sullivan, et al, 1973)

FIGURE 1. GEOGRAPHICAL AND CLIMATIC LOCATIONS OF LAND TREATMENT SITES VISITED.

TABLE 1. SUMMARY OF DATA COLLECTED DURING SITE VISITS

- Background Information
  - Contributory population, flows, loadings
  - Final disposition of wastewater
  - Budget
  - Instrumentation, electrical consumption
  - Analytical data
- Staffing
  - Certification
  - Background data
  - Preapplication and land application staffing
- Maintenance
  - Preventative maintenance program
  - Operation and maintenance manual
- Wastewater Preapplication Treatment System
  - Physical facilities (type and number)
  - Process flow diagram
- Land Treatment System
  - Wastewater storage
  - Wastewater distribution
  - Buffer zones, site access
  - Application rates
  - Soils information
  - Groundwater monitoring
- Facility Layout
  - Preapplication treatment
  - Land application system
- Land Application - Agricultural Viewpoint
  - Operational strategies (wastewater applications, time and amount)
  - Operational problems
  - Crop management
- Land Application - A Neighbor's Viewpoint
  - Problems
  - Changes

system. For example, a holding pond following secondary treatment may actually function as an oxidation pond, thereby appearing to be part of the preapplication treatment system. One could also consider the holding pond as nothing more than an effluent holding pond, however, and therefore, part of the land application system.

The second problem question, closely related to the budgetary dilemma, involved staffing requirements for the preapplication treatment and the land treatment systems. The problem involves dividing the hours which are spent daily into preapplication and land application treatment.

A further complication to both the budgetary and staffing information is afforded by the different operational practices at the treatment plants. For example, at one location the preapplication treatment and land treatment systems may be operated and maintained by the same staff, whereas at another facility, the duties at the land treatment facility may be shared by the wastewater treatment facility personnel and/or farmer. At a third facility, however, the operation and maintenance of the land application system may be performed entirely by a farmer. Therefore, only costs incurred by the municipality during the land treatment portion were included, and no attempt was made to calculate costs incurred by the farmer in the operation of the land application facility, as the majority of these costs would be incurred during irrigation of a normal farm.

An additional problem question concerned determining the land treatment operating strategy. The problem, however, was not how the facility was operated, but rather why the facility was operated in the mode that it was. Typically, it appeared that operational practices were gained through experience, and once practices were successful, no attempt was made to change the operation of the facility. Therefore, when questioned about the operation of the facility, the operators could typically respond about how something was done, but not necessarily why it was done.

EVALUATION OF CURRENT OPERATION AND MAINTENANCE PRACTICES

This section presents a summary of the information which was collected during the site visits. The 28 site visits included 18 slow rate, seven rapid infiltration, and four overland flow systems (one system was both slow rate and rapid infiltration). Table 2 presents background information on the land treatment systems. Similarly, Table 3 gives a description of the physical facilities at each land treatment site. Information relative to the operation and maintenance of the land treatment systems is contained in Table 4, with Table 5 presenting land treatment system loading rates. Data on groundwater monitoring are presented in Table 6 along with monitoring parameters and frequency.

TABLE 2. LAND TREATMENT SYSTEMS, BACKGROUND INFORMATION

Facility Name	Site Number	Type of System	Years in Operation	Adjacent Land Use[a]	Percent of Preapplication Effluent to Land Treatment	Drinking Water Source in Vicinity	Weather Data[b] Average Annual Temperature °C	Average Annual Precipitation m	Estimated Mean Annual Class A Pan Evaporation m
Village of Lake George WWTP	001	RI	41	R	100	Public	8.2	0.95	0.84
North Branch Fire District No. 1 WPCF	002	SR	5	R,C,A	100	Well	7.8	1.09	0.89
City of Hart WWTF	003	SR	6	A	100	Well	8.3	0.84	0.94
City of Fremont WWTP	004	SR	5	A	100	Well	8.9	0.84	1.02
Village of Ravenna STP	005	SR	11	R,A	100	Well	8.5	0.80	0.99
City of Wayland WWTP	006	SR	9	A	100	Well	8.8	0.82	1.02
Fontana Regional Plant No. 3	007	RI,SR	27	I,A,O	100	Public	17.6	0.32	1.75
Pomona Water Reclamation Plant	008	SR	50	R,C,I,A,O	Winter 33 Summer 66	Public	16.7	0.42	1.65
Whittier Narrows Water Reclamation Plant	009	RI	18	R,C	100	Public	16.7	0.42	1.65
Palmdale Water Reclamation Plant	010	SR	23	A	100	Public	16.4	0.20	1.78
Irvine Ranch Water District	011	SR	11	R,C,A,O	100	Public	16.6	0.31	1.52
City of Tulare WPCF	012	SR	35+	A	100	Well	17.4	0.24	2.29
City of Kerman WWTP	013	SR	4	A,I	100	Well	16.8	0.26	2.29
City of Manteca WWQCF	014	SR	17	A	100	Well	15.9	0.30	2.03
El Dorado Hills WWTP	015	SR	5	A,O	40	Public	13.1	1.01	1.65
U.S. Army COE, WES Overland Flow Site	016	OF	4	A	33	Public	18.8	1.31	1.52
Falkner WWTF	017	OF	3	A,R	100	Public	15.9	1.38	1.40
Easley Combined Utilities System Overland Flow Project	018	OF	2	A,R	100	Public	15.4	1.32	1.30
Town of Wareham WPCF	019	RI	8	R	100	Public	11.1	1.01	0.86
Chatham WPCF	020	RI	9	R	100	Well & Public	9.7	1.10	0.81
Town of Barnstable WPCF	021	RI	45	C,R	100	Public	11.1	1.01	0.86
Kendal/Crosslands Lagoon System	022	SR	7	R	100	Public	11.9	1.10	1.19
Landis Sewage Authority	023	RI	30	I	100	Public	12.2	1.02	1.14
Campbell Soup (Texas), Inc.	024	OF	16	C,I,A	100	Public	17.3	1.15	1.91
City of Coleman WWTP	025	SR	50	A	70	Public	18.6	0.68	2.41
City of Santa Anna WWTP	026	SR	14	A	100	Public	18.6	0.68	2.41
City of Winters WWTP	027	SR	56	A	100	Public	18.2	0.55	2.49
City of Sweetwater WPCP	028	SR	22	A	100	Public	17.4	0.56	2.54

---

[a] R = Residential
C = Commercial
I = Industrial
A = Agricultural
O = Other

[b] From nearest weather station.

Key

WWTP - Wastewater treatment plant
WPCF - Water pollution control facility
WWTF - Wastewater treatment facility
STP - Sewage treatment plant
WWQCF - Wastewater quality control facility
WPCP - Water pollution control plant

TABLE 3. LAND TREATMENT SYSTEMS, PHYSICAL FACILITIES

Facility Name	Site No.	Type of System	Instrumentation System	Wastewater Storage[a] days	Land Area Used[b] ha	Soil Type	Slope of Land[c]	Number of Groundwater Monitoring Wells	Wastewater Distribution System	Wastewater Application System
Village of Lake George WWTP	001	RI	No	0	2.2	Sand	Flat	24	G,P	Infiltration beds
North Branch Fire District No. 1 WPCF	002	SR	Yes	162	13.8	Silt, sand, loam	Steep	6	P	Fixed nozzles
City of Hart WWTF	003	SR	No	102	34.8	Sand, loam	Moderate	6	P	Gated pipe, ridge and furrow
City of Fremont WWTP	004	SR	No	472	24.1	Sand, loam	Flat	32	G,P	Border strip
Village of Ravenna STP	005	SR	No	297	8.1	Sand, clay	Flat	0	G	Border strip
City of Wayland WWTP	006	SR	No	258	31.6	Sand, loam, clay	Moderate	5	P	Center pivot, big gun spray
Fontana Regional Plant No. 1	007	RI,SR	No	0	20.3	Sand, loam	Flat	0	G,P	Infiltration beds, ridge & furrow
Pomona Water Reclamation Plant	008	SR	Yes	0[d]	29.1	Widely varying	Flat-steep	0	G,P	Spray, ridge and furrow
Whittier Narrows Water Reclamation Plant	009	RI	No	0	405+	Sand	Flat	16+	G	Infiltration beds
Palmdale Water Reclamation Plant	010	SR	No	42	279	Silt, sand, loam	Flat	4	P	Side-wheel roll spray
Irvine Ranch Water District	011	SR	Yes	98	607-809 (Seasonal)	Silt, sand, clay, loam	Flat-moderate	0	P	Spray, ridge and furrow, drip
City of Tulare WPCF	012	SR	No	28	205	Sand, loam	Flat	0	G	Border strip, ridge and furrow
City of Kerman WWTP	013	SR	No	3	87.8	Sand, loam	Flat	0	G,P	Ridge and furrow
City of Manteca WWQCF	014	SR	No	4	106	Sand, loam	Flat	9	G,P	Border strip
El Dorado Hills WWTP	015	SR	No	7	8.1	Silt, loam	Moderate	0	P	Spray
U.S. Army COE, WES Overland Flow Site	016	OF	Yes	N/A	0.50	Silt, loam	Flat-moderate	0	P	Trough distribution
Falkner WWTF	017	OF	No	118	1.06	Silt, loam, clay	Flat-moderate	0	P	Spray
Easley Combined Utilities System Overland Flow Project	018	OF	Yes	44	1.9	Loam, clay, sand	Moderate	5	P	Fixed nozzle, trough, open pipe
Town of Wareham WPCF	019	RI	No	0	1.6	Sand	Flat	0	G	Infiltration beds
Chatham WPCF	020	RI	No	0	0.38	Sand, loam	Flat	0	G	Infiltration beds
Town of Barnstable WPCF	021	RI	No	0	3.2	Sand, loam[e]	Flat	0	G	Infiltration beds
Kendal/Crosslands Lagoon System	022	SR	Yes	51	3.2	Silt, loam	Moderate	11	P	Spray
Landis Sewage Authority	023	RI	No	0	26.3	Sand	Flat	3	G,P	Infiltration beds
Campbell Soup (Texas), Inc.	024	OF	Yes	0	235	Clay	Moderate	0	P	Spray
City of Coleman WWTP	025	SR	No	0	23.1	Clay, loam, silt	Flat	0	G	Border strip
City of Santa Anna WWTP	026	SR	No	369	10.9	Clay, loam, silt	Flat	0	P	Side-wheel roll spray
City of Winters WWTP	027	SR	No	9	10.5	Silt, sand, clay, loam	Flat	0	G,P	Border strip
City of Sweetwater WPCP	028	SR	No	15	115	Silt, loam, clay	Flat	0	G,P	Border strip

---

[a] Includes potential storage, such as variable levels in oxidation ponds using 0.61 m (2.0 ft) minimum water depth regardless of whether or not system is operated this way. Based on current flow rate, not including precipitation or evaporation effects.

[b] Includes only land area in use, not land available for use.

[c] Flat 0-3%; moderate 3-8%; steep over 8%.

[d] An 11,356-m^3 storage basin is currently under construction.

[e] Imported sand has been used for replacement.

Key

WWTP	Wastewater treatment plant
WPCF	Water pollution control facility
WWTF	Wastewater treatment facility
STP	Sewage treatment plant
WWQCF	Wastewater quality control facility
WPCP	Water pollution control plant

TABLE 4. LAND TREATMENT SYSTEMS INFORMATION

Facility Name	Site No.	Type of System	Revenues Generated	Average Electrical Usage[a] kwh/mo	Type of Regulatory Permit[b]	O&M Manual Which Addresses Land Application On Hand?	System Operated as Designed?	Buffer Zone Size m	Public Access Controls
Village of Lake George WWTP	001	RI	0	1,365	PTQ	No	Yes	76	Woods
North Branch Fire District No. 1 WPCF	002	SR	0	4,700	OP	Yes	Yes	61	Fence and signs
City of Hart WWTF	003	SR	0	16,228	GWQ	Yes	Yes	15	Fence and signs
City of Fremont WWTP	004	SR	0	3,505	GWQ	Yes	Yes	15	Fence and signs
Village of Ravenna STP	005	SR	0	0	SWDQ	No	Yes	15	Fence and signs
City of Wayland WWTP	006	SR	0	14,000	GWQ	Yes	Yes	0	Fence and signs
Fontana Regional Plant No. 3	007	RI,SR	0	11,250	PTQ	No	Yes	91 RI basins 6 Citrus grove	Fence and signs--RI basins Signs--citrus grove
Pomona Water Reclamation Plant	008	SR	Gravity-$12.16/1,000 m^3 Pressure-$48.93/1,000 m^3[c]	16,933	PTQ	N/A	Yes	0	None
Whittier Narrows Water Reclamation Plant	009	RI	$16.21/1,000 m^3	0	PTQ	N/A	Yes	0	Fence and signs
Palmdale Water Reclamation Plant	010	SR	$4.05/1,000 m^3	0	PTQ,GWQ	N/A	No	0	Signs
Irvine Ranch Water District	011	SR	$32.43-$64.86/1,000 m^3	Not known	PTQ	N/A	Yes	0	None
City of Tulare WPCF	012	SR	City receives 25% of crop revenues	0	PTQ	Yes	Yes	0	Signs
City of Kerman WWTP	013	SR	$1,000/yr for water $181/ha/yr for land	194	PTQ	Yes	Yes	0	None
City of Manteca WWQCF	014	SR	$10.71/ha/yr for land	10,000	PTQ,GWQ	Yes	No	0	None
El Dorado Hills WWTP	015	SR	$100/month+$31/1,000 m^3	Not known	PTQ,SWDQ	No	No	0	None
U.S. Army COE, WES Overland Flow Site	016	OF	0	Not known	None	Yes	Yes	400	Signs
Falkner WWTF	017	OF	0	360	SWDQ	Yes	Yes	0	Fence and signs
Easley Combined Utilities System Overland Flow Project	018	OF	0	2,326	None	Yes	No	15	Fence and signs
Town of Wareham WPCF	019	RI	0	0	SWDQ	Yes	Yes	30	Fence
Chatham WPCF	020	RI	0	0	OP	Yes	Yes	305	None
Town of Barnstable WPCF	021	RI	0	0	OP	Yes	Yes	30	Fence
Kendal/Crosslands Lagoon System	022	SR	0	3,630	PTQ	Yes	Yes	46	One field--fence and signs Other field--none
Landis Sewage Authority	023	RI	0	3,460	OP	No	Yes	0	None
Campbell Soup (Texas), Inc.	024	OF	0	Not known	SWDQ	No	Yes	30+	Fence
City of Coleman WWTP	025	SR	$129.87/ha/yr for land	0	SWDQ	Yes	Yes	6	Fence and signs
City of Santa Anna WWTP	026	SR	Farmer pays pumping cost	727	OP	Being written	Yes	305	Fence
City of Winters WWTP	027	SR	$8.09/ha/yr for entire site	3,000	OP	No	Yes	30	Fence
City of Sweetwater WPCP	028	SR	0	2,700	OP	N/A	Yes	15	Fence and signs

---

[a] Does not include electrical usage by end users unless paid by authority.

[b] OP - Operating permit
PTQ - Preapplication treatment quality
SWDQ - Surface-water discharge quality
GWQ - Groundwater quality

[c] City of Pomona Water Department purchases water for $9.26/1,000 m^3.

Key

WWTP - Wastewater treatment plant
WPCF - Water pollution control facility
WWTF - Wastewater treatment facility
STP - Sewage treatment plant
WWQCF - Wastewater quality control facility
WPCP - Water pollution control plant

TABLE 4. LAND TREATMENT SYSTEMS INFORMATION (continued)

Facility Name	Site No.	Type of System	Land Treatment System Management	Surface Runoff Collected/Diverted	Months System in Use[a]	Types of Crops	Crop Use	Who Harvests Crop?	Are Farming Practices Different?	Maximizing Crop Production or Wastewater Disposal
Village of Lake George WWTP	001	RI	Wastewater agency	Yes	1-12	Not applicable	-	-	N/A	N/A
North Branch Fire District No. 1 WPCF	002	SR	Wastewater agency	Yes	1-12	Maples, beeches, birches, white pine, spruce, fir	Not applicable	-	N/A	Wastewater
City of Hart WWTF	003	SR	Wastewater agency	Yes	4-11	Pine, hardwood, uncultivated	Not applicable	-	N/A	Wastewater
City of Fremont WWTP	004	SR	Wastewater agency	Yes	4-11	Alfalfa, oats, rye	Animal feed	Custom farmer	Yes	Wastewater
Village of Ravenna STP	005	SR	Wastewater agency	Yes	4-11	Uncultivated	Not applicable	-	N/A	Wastewater
City of Wayland WWTP	006	SR	Wastewater agency[b]	Yes	5-9	Alfalfa, timothy, grass, clover	Animal feed	Custom farmer	Yes	Wastewater
Fontana Regional Plant No. 3	007	RI SR	Wastewater agency and farmer	Yes	RI 1-12 SR 4-10	SR-grapefruits, oranges	Human consumption	Farmer	Yes	Crops
Pomona Water Reclamation Plant	008	SR	City of Pomona and end users	No	1-12	Landscape, alfalfa, tomatoes, corn, oats, barley, citrus	Human and animal consumption	Individual farmers	No	Crops
Whittier Narrows Water Reclamation Plant	009	RI	LACFCD	Yes	1-12	Not applicable	-	-	N/A	N/A
Palmdale Water Reclamation Plant	010	SR	Farmer	No	2-10	Alfalfa, oats	Animal feed	Farmer	No	Crops
Irvine Ranch Water District	011	SR	Wastewater agency, farmer and home owners assoc.	No	1-12	Tomatoes, peppers, corn, broccoli, cauliflower, landscape	Human consumption	Farmer	Yes	Crops
City of Tulare WPCF	012	SR	Farmer	No	1-12	Wheat, barley, oats, cotton, corn	Animal feed	Farmer	Yes	Crops
City of Kerman WWTP	013	SR	Farmer	No	1-12	Alfalfa, sugar beets, barley, oats, cotton, almonds	Human and animal consumption	Farmer	Yes	Crops
City of Manteca WWQCF	014	SR	Farmer	Yes	1-12	Barley, oats, corn	Cattle feed	Farmer	No	Wastewater
El Dorado Hills WWTP	015	SR	Golf course	No	1-12	Landscape	-	-	N/A	N/A
U.S. Army COE, WES Overland Flow Site	016	OF	Wastewater agency (COE)	Yes	1-12	Reed canary, fescue, perennial rye, Bermuda	Tested and discarded	COE	N/A	Wastewater
Falkner WWTF	017	OF	Wastewater agency	Yes	1-12	Harding grass, coastal Bermuda, reed canary, fescue	Left in field	Operator	N/A	Wastewater
Easley Combined Utilities System Overland Flow Project	018	OF	Wastewater agency and Clemson Univ.	Yes	1-12	Fescue, rye	Erosion control	Custom farmer	N/A	Wastewater
Town of Wareham WPCF	019	RI	Wastewater agency	Yes	1-12	Not applicable	-	-	N/A	N/A
Chatham WPCF	020	RI	Wastewater agency	Yes	1-12	Not applicable	-	-	N/A	N/A
Town of Barnstable WPCF	021	RI	Wastewater agency	Yes	1-12	Not applicable	-	-	N/A	N/A
Kendal/Crosslands Lagoon System	022	SR	Wastewater agency	No	1-12	Beeches, maples, poplar, oak	Not applicable	-	N/A	Wastewater
Landis Sewage Authority	023	RI	Wastewater agency	Yes	1-12	Not applicable	-	-	N/A	N/A
Campbell Soup (Texas), Inc.	024	OF	Campbell Soup	Yes	1-12	Reed canary, fescue, red top, rye	Cattle feed	Custom farmer	N/A	Wastewater
City of Coleman WWTP	025	SR	Wastewater agency and farmer	Yes	1-12	Coastal Bermuda	Pasture	-	Yes	Wastewater
City of Santa Anna WWTP	026	SR	Wastewater agency and farmer	Yes	1-12	Alfalfa, Johnson grass	Pasture	-	Yes	Wastewater
City of Winters WWTP	027	SR	Farmer	Yes	1-12	Coastal Bermuda, Sudan grass	Pasture	-	Yes	Wastewater
City of Sweetwater WPCP	028	SR	Farmer	Yes	1-12	Coastal Bermuda, Sudan, Johnson, and Rescue grasses, oats, and wheat	Pasture, animal feed	Farmer	Yes	Crops

---

[a] January = 1, December = 12

[b] Farmer to manage in future.

Key

WWTP - Wastewater treatment plant
WPCF - Water pollution control facility
WWTF - Wastewater treatment facility
STP - Sewage treatment plant
WWQCF - Wastewater quality control facility
WPCP - Water pollution control plant

TABLE 5. LAND TREATMENT SYSTEM LOADING RATES

Facility Name	Site Number	Type of System	Hydraulic		Organic	Suspended Solids	Nutrients		
			mm/wk	m/yr	kg BOD_5/ha/yr	kg SS/ha/yr	kg NH_3-N/ha/yr	kg NO_3-N/ha/yr	kg T-P/ha/yr
North Branch Fire District No. 1 WPCF	002	SR	21.8	1.1	40.7	45.2	5.4	63.7	15.6[a]
City of Hart WWTF	003	SR	69.5	2.4	1,208	2,101	--	--	49.3[a]
City of Fremont WWTP	004	SR	76.2	2.6	316	817	--	--	87
Village of Ravenna STP	005	SR	--	1.2	--	--	--	--	--
City of Wayland WWTP	006	SR	42.2	1.1	287	--	--	--	--
Fontana Regional Plant No. 3	007	SR	54.6	1.6	1,623	1,247	472	5.9	410
Pomona Water Reclamation Plant	008	SR			Cannot be calculated				
Palmdale Water Reclamation Plant	010	SR	33.0	1.4	637	1,699	99.1	--	157[a]
Irvine Ranch Water District	011	SR			Cannot be calculated				
City of Tulare WPCF	012	SR	43.2	2.3	2,253	4,070	454	--	--
City of Kerman WWTP	013	SR	17.0	0.89	89	53	--	--	--
City of Manteca WWQCF	014	SR	58.4	3.0	1,471	1,382	445	16.9	--
El Dorado Hills WWTP	015	SR			Cannot be calculated				
Kendal/Crosslands Lagoon System	022	SR	40.6	2.1	320	428	219	--	149[a]
City of Coleman WWTP	025	SR	32.3	1.7	67.2	16.8	--	--	--
City of Santa Anna WWTP	026	SR	18.3	0.95	266	578	--	--	--
City of Winters WWTP	027	SR	76.2	4.0	1,775	2,365	--	--	--
City of Sweetwater WPCP	028	SR	45.7	1.2	215	132	--	--	--
Village of Lake George WWTP	001	RI	1,130	40.5	23,862	8,897	--	--	--
Fontana Regional Plant No. 3	007	RI	330	17.3	17,162	12,771	4,995	43.1	4,335
Whittier Narrows Water Reclamation Plant	009	RI	--	49.7[b]	--	--	--	--	--
Town of Wareham WPCF	019	RI	2,110	27.1	4,103	5,471	--	--	--
Chatham WPCF	020	RI	Winter 380 Summer 720	28.8	5,616	4,405	--	--	--
Town of Barnstable WPCF	021	RI	--	12.0	--	--	--	--	--
Landis Sewage Authority	023	RI	400	21.0	--	--	--	--	--
U.S. Army COE, WES Overland Flow Site	016	OF	63.5-254	3.3-13.2	87.6-349	139-555	55.0-222	--	39.3-158
Falkner WWTF	017	OF	17.8[c]	--	--	--	--	--	--
Easley Combined Utilities System Overland Flow Project	018	OF	Raw 119 Pond 103-193	-- --	11,810 1,446-2,740	10,982 3,098-5,871	944 42.8-80.7	79.9 28.0-52.8	172 64.0-121
Campbell Soup (Texas), Inc.	024	OF	40.6	2.1	12,790	5,595	370[d]	--	160

---

[a] Phosphorus measured as PO_4.

[b] Based on total water infiltration, not only reclaimed water.

[c] Design application rate.

[d] Total - N.

Key

WWTP - Wastewater treatment plant
WPCF - Water pollution control facility
WWTF - Wastewater treatment facility
STP - Sewage treatment plant
WWQCF - Wastewater quality control facility
WPCP - Water pollution control plant

TABLE 6. GROUNDWATER MONITORING DATA

Facility Name	Facility Number	Type of System	Number of Wells	Groundwater Monitoring Parameters	Sample Frequency
Village of Lake George WWTP	001	RI	24	Wells installed by Rensselaer Polytechnic Institute for research purposes only	-
North Branch Fire District No. 1 WPCF	002	SR	6	pH, alkalinity, hardness, sulfate, chloride, ammonia-N, nitrate-N, phosphate	1/month when not frozen
City of Hart WWTF	003	SR	6[a]	Static water elevation, chloride, specific conductance, pH Hardness, alkalinity, ammonia-N, nitrate-N, phosphorus, MBAS, COD	1/month 1/year
City of Fremont WWTP	004	SR	32	Static water elevation, chloride, specific conductance pH, hardness, alkalinity, ammonia-N, nitrate-N, nitrite-N, phosphorus, sulfate	4/year 1/year
City of Wayland WWTP	005	SR	5	No samples are taken due to problems with wells. New wells are to be installed.	--
Whittier Narrows Water Reclamation Plant	009	RI	16[a]	Major minerals, nitrogen compounds, COD, BOD, TDS, electrical conductance, pH, odor Trace metals, chlorinated hydrocarbons	4/year 1/year
Palmdale Water Reclamation Plant	010	SR	2	Various wastewater parameters measured in farmer's two irrigation wells	2/year
City of Manteca WWQCF	014	SR	9	Static water elevation, ammonia-N, nitrite-N, nitrate-N	4/year
Easley Combined Utilities System Overland Flow Project	018	OF	5	Groundwater monitoring for research purposes only	-
Kendal/Crosslands Lagoon System	022	SR	7	Static water elevation, pH, ammonia-N, nitrite-N, nitrate-N, phosphate, fecal coliforms	4/year
Landis Sewage Authority	023	RI	3	Water table elvation	Continuous

---

[a] Four local domestic wells also monitored.

Of the 28 sites visited, facility 002 (North Branch Fire District No. 1, Dover, Vermont) was located in the coldest area, with a mean annual temperature of 7.8°C (46.0°F). The Utica, Mississippi overland flow site was located in the warmest area, with a yearly average temperature of 18.8°C (65.8°F). Precipitation ranged from a high of 1.38 m/yr (4.53 ft/yr) at the Falkner, Mississippi facility to a low of 0.20 m/yr (0.66 ft/yr) at the Palmdale, California Water Reclamation Plant. Yearly annual estimated Class A pan evaporation ranged from a high of 2.54 m (8.3 ft) in Sweetwater, Texas, to a low of 0.81 m (2.7 ft) in Chatham, Massachusetts.

Wastewater storage at the facilities ranged from 0 to a high of 472 days at facility 004 (City of Fremont, Michigan). Storage included any potential storage due to a variable level in an oxidation pond, plus storage in holding basins. Of interest, is the fact that none of the seven rapid infiltration systems visited had on-site storage. The overland flow site at facility 024 (Campbell Soup, Paris, Texas) had no storage, whereas the other overland flow sites had storage based on a variable level in the preapplication treatment oxidation ponds. There were only two slow-rate systems which had no provisions for wastewater storage; these were facilities 008 and 025 (Pomona, California Water Reclamation Plant, and the Coleman, Texas Wastewater Treatment Plant). In both of these plants, however, provisions existed for surface discharge.

The land area receiving wastewater varied from a low of 0.38 ha (0.94 acres) at the Chatham, Massachusetts facility, to a high of 809 ha (2,000 acres) associated with the Irvine Ranch Water District, California. The land area usage has been plotted as a function of flow rate in Figure 2. As would be expected for the three different types of systems, three distinct areas on the graph are prevalent. The lowest land requirement is for the rapid infiltration systems. The highest land requirement is for the slow-rate systems. In the middle area are the four overland flow plants. Facility 024 (Campbell Soup, Paris, Texas) appears slightly higher on the curve than some of the other overland flow systems. This can be accounted for by a recent expansion, and the fact that the facilities receive industrial wastewater with a high organic loading. Also plotted in Figure 2 are the application land area requirements for moderately-favorable conditions, as taken from "Water Reuse and Recycling," Volume 2, OWRT/RU-79-2, U.S. Department of Interior, 1979 (2). Since the smallest flow contained in this report is 0.044 m^3/s (1.0 mgd), the plots are extrapolated for lower values. The field data compare favorably with the OWRT data.

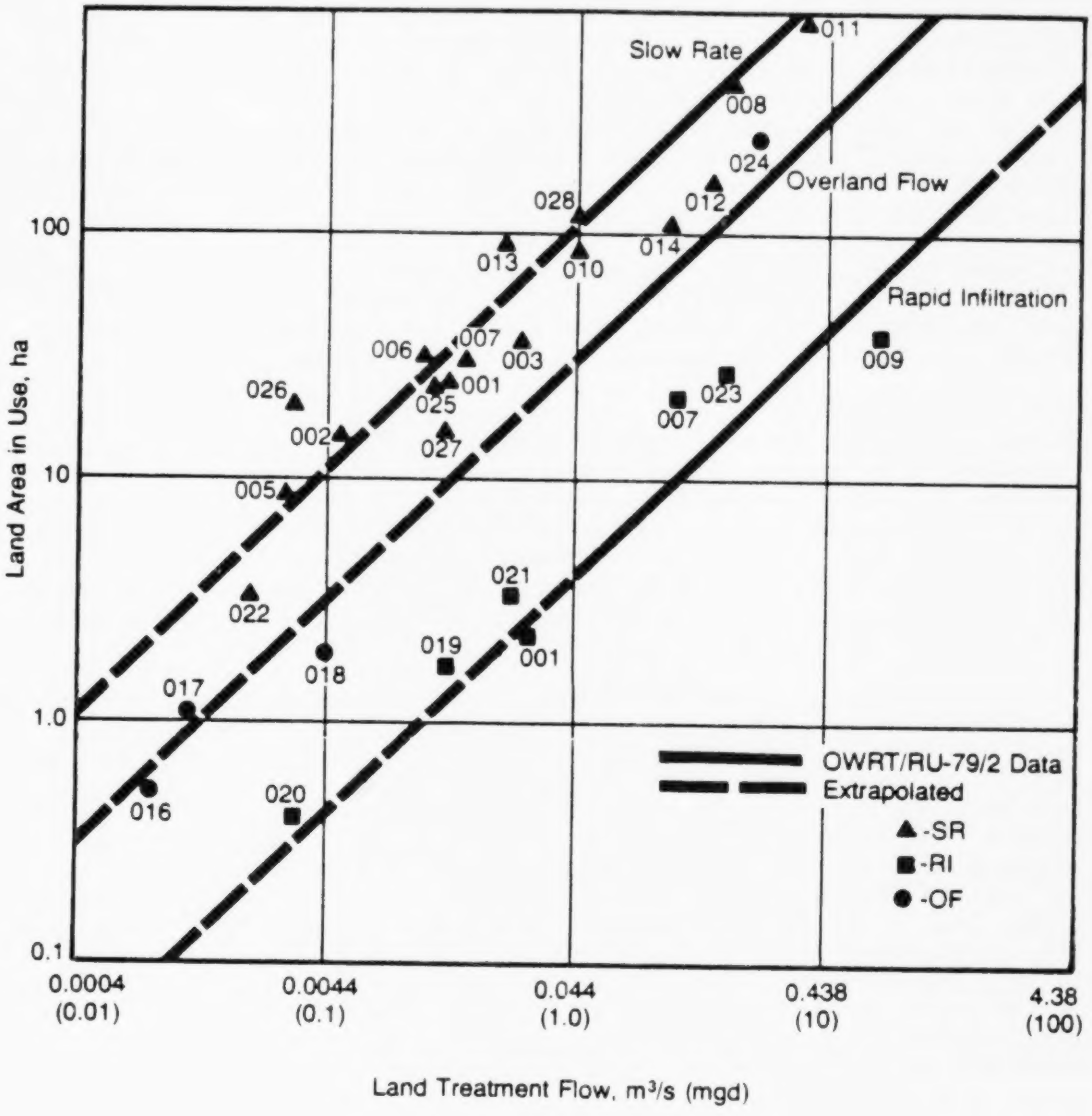


FIGURE 2. LAND AREA USED AS A FUNCTION OF FLOW RATE

A wide variety of wastewater distribution equipment and application system types were seen during the survey. In addition, at nine of the 28 sites, wastewater was distributed by both gravity and pumping. At three of these sites, i.e., facilities 001,007, and 023, the older portions of the systems received gravity flow, while pumping was required for the newer portions.

A variety of contractual agreements exist, and typically these agreements are for the slow-rate system, with the exception of facility 009 (Whittier Narrows Water Reclamation Plant, California) where wastewater is purchased for groundwater recharge. In the remaining facilities, the agreements typically are for the purchase of wastewater or for rental of a portion of the city-owned land, with the stipulation that the wastewater will be utilized. At facility 012 (Tulare, California), the stipulation is that the city will receive 25 percent of the crop-generated revenues.

Of the sites visited, all of the rapid infiltration and overland flow systems were operated 12 months out of the year. It should be remembered, however, that the overland flow systems were all located in mild climates. Of the 18 slow-rate systems, only six are operated less than 12 months of the year. Of these, the citrus crop irrigation at facility 007 (Fontana, California Regional Plant) is included. In this case, however, as there is a rapid infiltration system also available, the slow-rate system is not operated during the colder months.

The types of crops grown and the ultimate use of the crops are presented in Table 4 for the slow-rate and overland flow sites. Of the seven rapid infiltration sites visited, only the Chatham, Massachusetts facility had any major plant growth in the basins. This was just weed growth which had not been removed.

At the remaining sites (with the exception of Ravenna, Michigan), a wide range of crops are grown. At three sites, trees are irrigated but not harvested. At the Utica, Mississippi overland flow site, the vegetation was tested and discarded. In Falkner, Mississippi the vegetation was cut and left in the field. At the Easley, South Carolina overland flow site, the grass was baled; it is currently used only for erosion control, as permission has not yet been granted for it to be used as animal feed. At the remaining sites, crops are grown and used for either human or animal consumption.

At the 13 facilities where the major objective of the land treatment system was crop production, the superintendent or foreman involved was queried as to whether or not the farming practices were different than at neighboring farms of equal soil type growing the same crop. At only three facilities were the farming practices the same as practices at neighboring farms.

LAND TREATMENT SYSTEM STAFFING AND OPERATION AND MAINTENANCE

The staffing requirements for both the preapplication and land treatment systems were analyzed and then compared to numbers presented in the literature. In addition, data pertaining to the number of shifts per day and days per week that the systems are staffed were collected. Utilizing these data, the information in Figure 3 was calculated, which presents the staffing for the three land treatment systems (independent of preapplication treatment) as a function of facility size. Staffing requirements were also compared to OWRT data for the land treatment portion of the facility.

The slow rate staffing requirements were typically less than reported in the OWRT report, whereas the rapid infiltration and overland flow staffing requirements are in general agreement.

Based on the limitations of the data collected and the amount of data collected, the following conclusions can be reached: 1) For the slow-rate land treatment system, the staffing requirement is independent of the degree of preapplication treatment; 2) For the rapid infiltration system, the labor required decreases as the degree of preapplication treatment increases; 3) No conclusions should be reached for the overland flow systems due to the insufficiency of data; 4) For the same degree of preapplication treatment, slow-rate land treatment systems were less labor intensive than rapid infiltration systems.

As was done with staffing, the operations and maintenance costs were compared to the OWRT data, and the results are presented in Figure 4. As was seen with the staffing requirements (and also because of) the slow-rate systems were typically less expensive than OWRT data, whereas the rapid infiltration and overland flow systems were in general agreement. A major cause of this apparent disparity for slow-rate staffing and operation and maintenance costs being typically lower than OWRT data is caused by the system being operated in conjunction with a local farmer. The farmer incurs a portion of the costs and therefore the municipality need not incur the cost. Furthermore, based on the visits, operations are improved by joint operation.

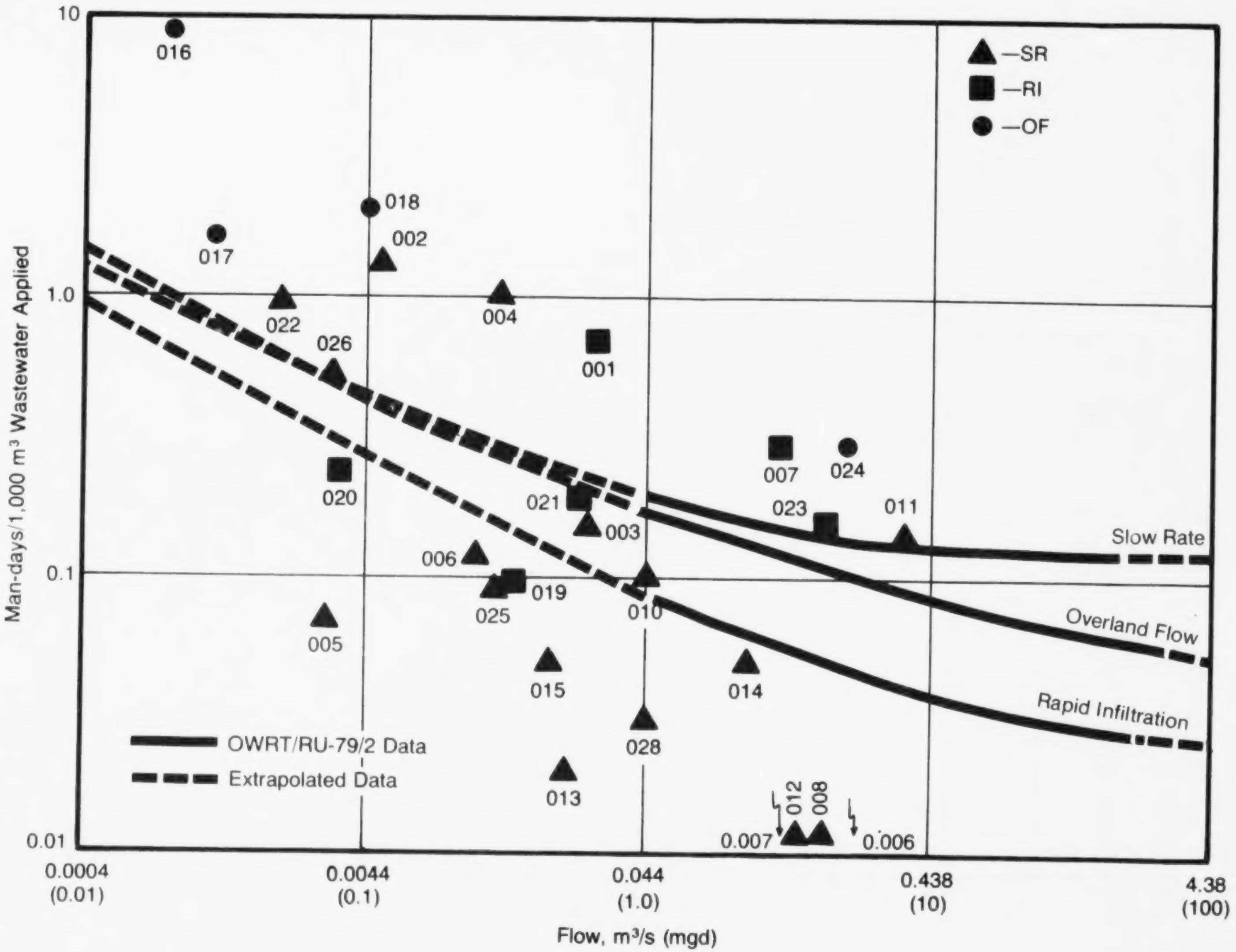


FIGURE 3. LAND TREATMENT STAFFING

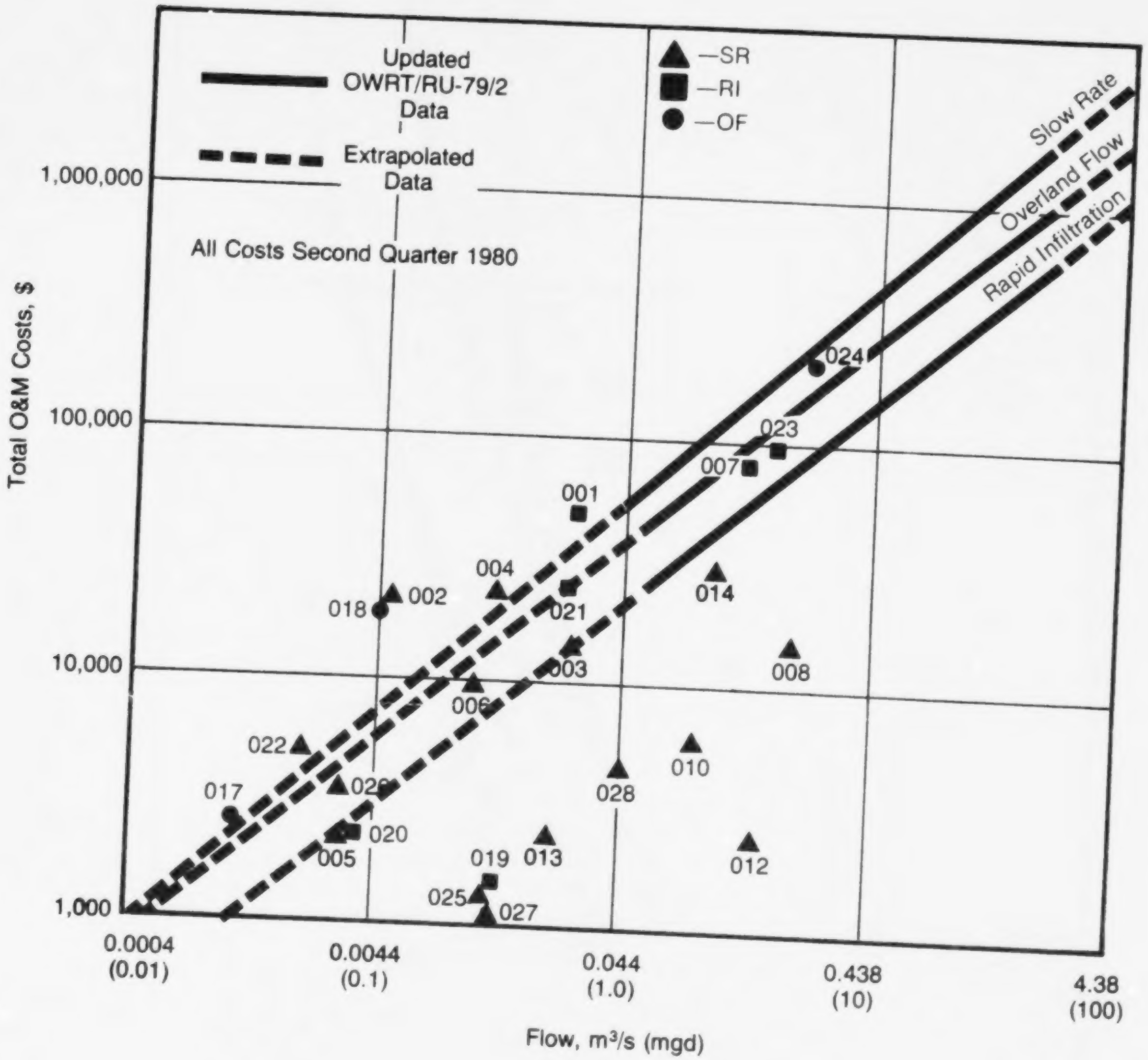


FIGURE 4. LAND TREATMENT OPERATIONS AND MAINTENANCE COSTS

Given the wide range of facilities which were visited, it is not surprising that both preapplication and land application treatment operation and maintenance unit costs vary greatly. The least expensive preapplication treatment cost was \$0.011/m^3 (\$0.04/1,000 gal), whereas the most expensive preapplication treatment facility cost was \$0.725/m^3 (\$2.74/1,000 gal). The land treatment operation and maintenance costs also varied widely, with the least expensive facility costing \$0.0005/m^3 (\$0.002/1,000 gal), whereas the most expensive facility cost \$0.207/m^3 (\$0.78/1,000 gal). The total treatment operation and maintenance cost, which is more than likely the most accurate cost, varied from a low of \$0.014/m^3 (\$0.05/1,000 gal) to \$0.744/m^3 (\$2.82/1,000 gal).

Based on the small sample size and the various limitations of the cost data collected, the following conclusions can be made utilizing the cost data collected: 1) The slow-rate land treatment operation and maintenance costs are unaffected by degree of preapplication treatment; 2) The rapid infiltration system operation and maintenance costs decrease as the degree of preapplication treatment increases.

EVALUATION OF OPERATION AND MAINTENANCE PRACTICES

The equipment for any land treatment system consists basically of piping, pumps, controllers, and application equipment. With the exception of the wastewater application equipment, wastewater treatment plant maintenance personnel should be familiar with all of the equipment, and its operation should not be a problem. With minimal personnel training, the maintenance of wastewater application equipment should pose no major problem.

Although the performance of a land treatment system must be based on circumstantial evidence (with the exception of the overland flow system), it would appear that the majority of facilities are well run, and their performance is in line with typical performance specifications.

Based on operation of the land treatment system (without regard to regulatory restraints), it is believed that a slow-rate land treatment system can operate without major problems with a minimum of primary preapplication treatment. Similarly, a rapid infiltration system can operate with a minimum of primary preapplication treatment if the required bed maintenance is practiced. It appears that the overland flow system can operate successfully with a minimum of preliminary (screening and grit removal) treatment.

DESIGN DEFICIENCIES

The most common preapplication treatment design deficiency involved preapplication ponds which were unprotected from the effects of erosion caused by wind-induced waves.

A wide variety of design deficiencies were noted with regard to the land treatment systems. Only at one location were the design deficiencies severe enough to substantially hamper facility operations. The design deficiencies included: unnecessary pumping; insufficient storage volume; improper nozzle selection; lack of consideration of the effect of soil type and texture during selection of irrigation equipment; application areas subject to public access; and improper grading causing ponding.

REFERENCES

1. Sullivan, R.H., et al. "Survey of Facilities Using Land Application of Wastewater". EPA 430/9-73-006, NTIS No. PB-227351, U.S. Environmental Protection Agency, Washington, D.C., July 1973.

2. U.S. Department of the Interior, Office of Water Research and Technology. "Water Reuse and Recycling", Volume 2, Evaluation of Treatment Technology. OWRT/RU-79/2, April 1979.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

SESSION NO. 2

Improving the Performance of Conventional Wastewater Treatment Processes

PAPER NO. 4

MAKING-DO WITH CLARIFIER HYDRAULIC OVERLOAD

by

Robert M. Crosby
President

Crosby, Young and Associates, Inc.
1201 E. 15th Street, Suite 108
Plano, Texas 75074

MAKING-DO WITH CLARIFIER HYDRAULIC OVERLOAD

Robert M. Crosby, President
Crosby, Young and Associates, Inc.

INTRODUCTION

In 1977, the engineering services firm: Crosby, Young and Associates, was organized with the specific purpose of finding ways of improving the hydraulic characteristics and solids separation effectiveness of settling tanks. The idea was born during a brief hydraulic study of the secondary clarifiers at the Trinity River Authority's 60 mgd Central Wastewater Treatment Plant in Grand Prairie, Texas. Naively, the writer had applied open-water dye tracer techniques to a tank to define the throughflow route of the bulk fluid, in the expectation that the fluid path would also show the most likely route of solids transport. It should be no surprise to anyone that the guess was a good one.

The general procedure was developed by physical oceanographers to trace the route and ultimate fate of pollutants discharged to natural waters. Usually, a boat was steered over a defined course while towing sensors or taking frequent samples to define the three-dimensional distribution of indicative parameters such as temperature, dissolved oxygen, or the concentration of an injected tracer dye. For the first clarifier flow pattern study, we chose one of these oceanographer's tools, continuously injected Rhodamine WT, a stable fluorescent dye. The test clarifier is shown in cutaway, Figure 1. We were interested in flow phenomena in a vertical longitudinal section, between the inlet and weir region, from top to bottom. Our "boat" was the traveling bridge. The resulting contours of equal dye concentration for one sampling run are shown in Figure 2. From this, we were able to estimate an excessively fast transport of fluid directly from the bottom inlet ports to the overflow weirs, with a dead region at the upper right.

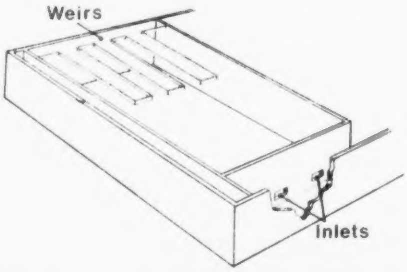


Figure 1. Cutaway view of a rectangular secondary clarifier.

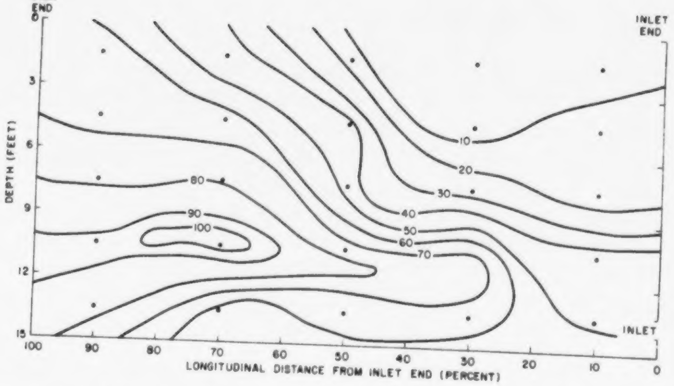


Figure 2. Isolines of dye concentration in a rectangular secondary clarifier.

To interrupt the high velocity jets and provide better vertical distribution of the incoming mixed liquor, the design engineer simply placed half-cylinders of pipe on the clarifier floor, 6 inches from the inlet wall, Figure 3. Monthly average effluent total suspended solids and associated BOD immediately dropped dramatically, Table 1. Using longer-term data, TSS dropped from 84 to 17 mg/l, a reduction of 79%. Material and labor cost for modifications to the four secondary clarifiers was $20,000.

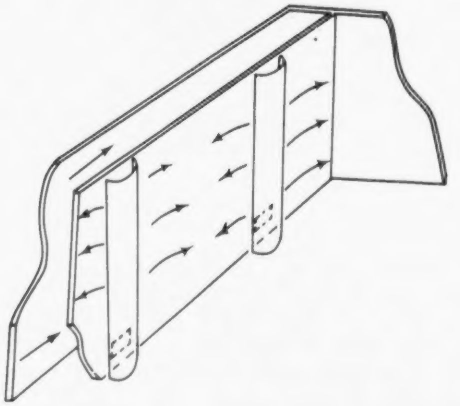


Figure 3. Baffling for bottom inlet ports.

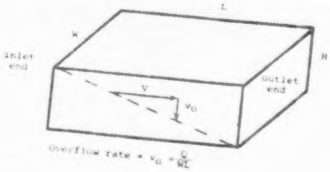
Table 1. Effluent Quality Before and After Baffling, TRA Central.

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BOD	64	80	75	56	17	33	31
TSS	60	43	56	37	14	17	20

▲
Baffle installed

WHAT IS HYDRAULIC OVERLOAD?

The "Ten State Standards"(1) place limits on overflow rate: for a conventional activated sludge secondary, 1200 gpd/sq ft for peak hourly effluent rate. Most readers will recall that surface area overflow rate is derived from Camp's(2) ideal geometric derivation, Figure 4. If fluid moves uniformly, horizontally in any cross-section, v_o is the minimum vertical velocity for all particles which will settle out completely. In this ideal case, v_o is exactly equal to effluent rate divided by surface area. Thus, surface area overflow rate. Not everyone recognizes that the same geometric model can be used to derive v_o which does not include surface area at all.



However:

$$v_o = \frac{H}{T} \qquad \text{where } T = \text{time}$$

$$v_o = \frac{VH}{L}$$

Figure 4. Camp's geometric settling zone model with alternate derivations.

But, by definition of nationally or locally accepted design standards, a clarifier is hydraulically overloaded if the surface area is too small for a given effluent rate.

REALITY

Unfortunately, most real clarifiers don't behave much like the ideal model. Figure 5 contrasts an ideal flow pattern assumed by Camp's model with the kind of pattern more commonly observed. Note that the upflow occurs over a relatively small fraction of the surface area. Henceforward in this presentation, real flow patterns will be described, with emphasis on simple modifications which were successful in making the clarifiers behave more ideally.

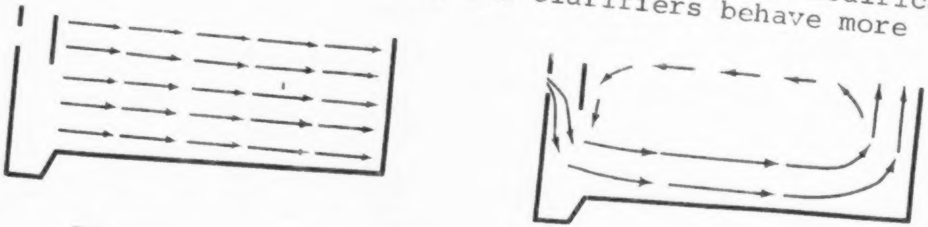


Figure 5. Ideal versus real flow patterns.

MAKING REAL CLARIFIERS WORK BETTER

To date, we have conducted analyses of 13 full-scale operating clarifiers. Of the 13, 12 were found to have either internal or upstream problems which degraded their effectiveness in capturing solids. One of the most common problems, the subject of considerable honest controversy, is the sludge blanket.

Importance of Blanket Control

What is a sludge blanket? Various optical and sonic sensors are marketed which provide an indication of a change in some fuzzily defined property of the water column at a certain depth. One very simple device, called a Sludge Judge, lets the operator see a sample of the fluid column and judge the depth of mostly-compacted solids. In the scientific literature one often finds a fixed concentration, such as 2000 mg/l, defined as a blanket. In fact, we felt compelled to make up a new term: Virtual Blanket, to describe the depth above which horizontal flow occurs, usually in a zone of fluidized solids.

To illustrate this, Figure 6(a,b,c) is a series of snapshots of dye concentrations in a radial section of a peripheral feed, peripheral overflow secondary after 35, 70, and 105 min.

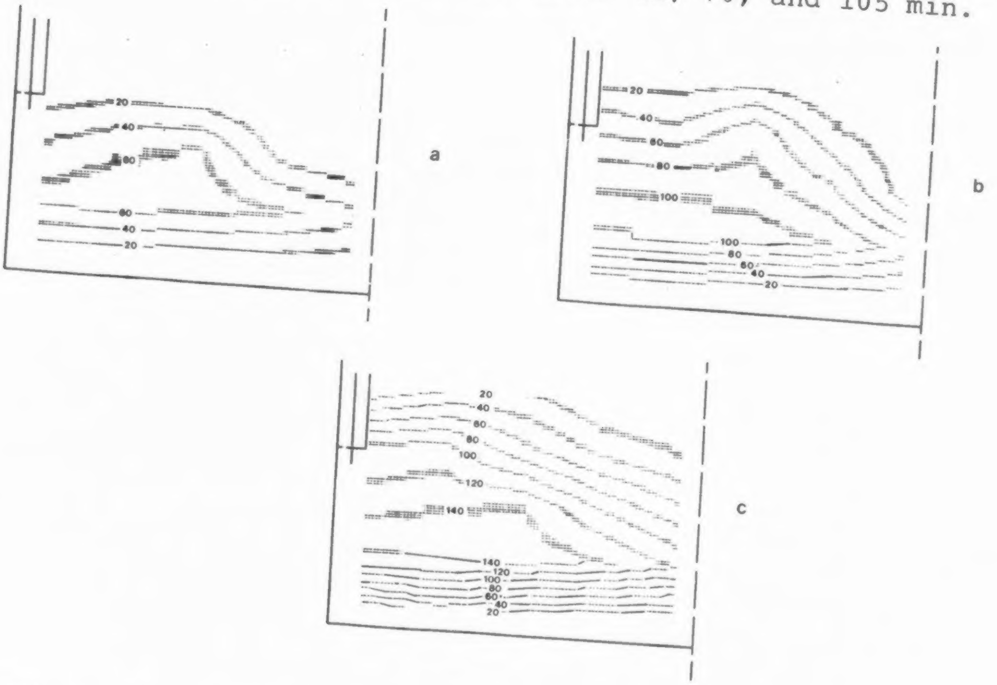


Figure 6. Peripheral feed clarifier flow pattern time-series, 35, 70, and 105 min, 65% of design hydraulic load.

In all of these, it can be clearly seen that the most prominent horizontal flow is occurring approximately 4 ft from the tank's bottom, indicated by the lower portion of the 140 parts per billion (ppb) dye contour in Figure 6c. When we look at the distribution of the square-root of solids concentrations in the same radial section, Figure 7, we see that the still-fluid part of the blanket falls between the 20 and 40 contours, which by squaring, are translated to a range of 400-1600 mg/l. All the snapshots of this flow pattern test series were made at a controlled overflow rate of 65% of the clarifier's design overflow rate.

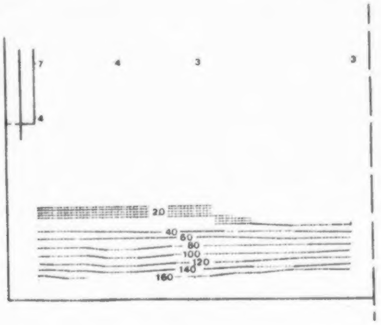


Figure 7. Peripheral feed clarifier square-root of TSS distribution, 65% of design hydraulic load.

At 100% of design hydraulic loading, the same clarifier produced a similar time series with a modest virtual blanket of 4 ft thickness. Figure 8a is the flow picture at 105 min. The 160 ppb contour is most representative of the horizontal flow depth, again 4 ft from the bottom. Figure 8b shows the square-root of TSS distribution during this test series. The 20 contour, representing 400 mg/l of solids was somewhat deformed by the flow.

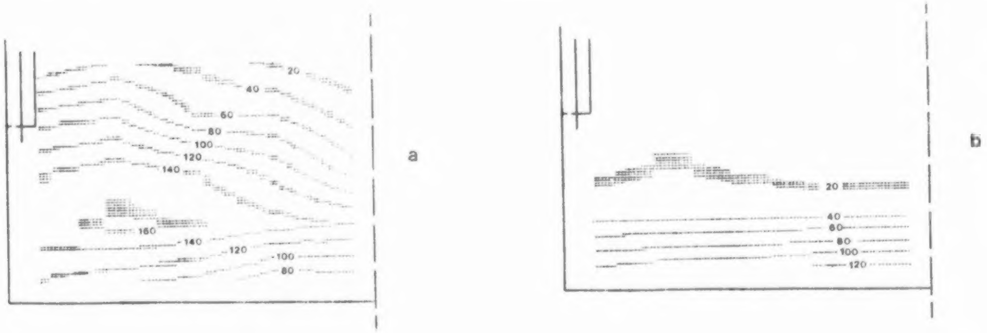


Figure 8. Peripheral feed clarifier flow pattern after 105 min (a) and the square-root of TSS distribution (b), 100% design hydraulic load, 4 ft blanket.

At the same flow rate with a virtual blanket 7 ft from the bottom, Figure 9a, the pattern of flow is disturbed; Figure 9b is suggestive of turbulent eddies at the left-hand side. From subsequent flow pattern tests elsewhere, these eddies seem to be characteristic of flows in cases where the blanket is in close proximity to the inlet baffle, resulting in a relatively small cross-sectional area for initiation of horizontal flow.

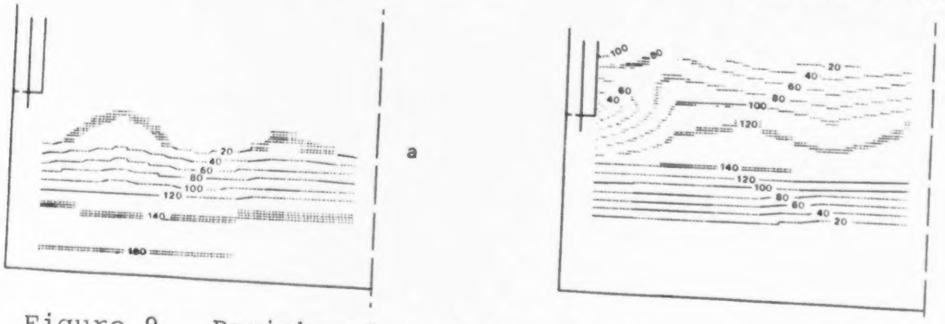


Figure 9. Peripheral feed clarifier square-root of TSS distribution (a) and disturbed flow pattern (b), 100% design hydraulic load, 7 ft blanket.

In an extreme case, the blanket may rise to a depth at which the lower extremity of the inlet baffle is actually covered by a high blanket. In the case shown in Figure 10a a bulking sludge was the cause. The upward curving contours just outside the feedwell are suggestive of a partial solids blowout at this location, but Figure 10b shows that horizontal flows, best defined by the 80 ppb contour, were occurring in a fluidized solids zone of between 1600 and 2500 mg/l concentration. Effluent quality based on TSS was excellent at the time.

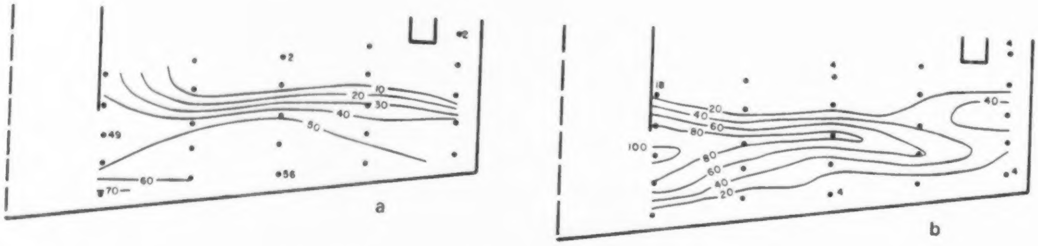


Figure 10. Centerfeed clarifier, bulking sludge distribution (a) and resultant flow pattern in 19 min (b).

One plant we studied briefly, maintains consistently low effluent TSS by means of a high return sludge rate which essentially strips the blanket, Figure 11a. There is some tendency for the throughflow to climb up the peripheral wall, Figure 11b, but the zero-blanket practice works for this plant.

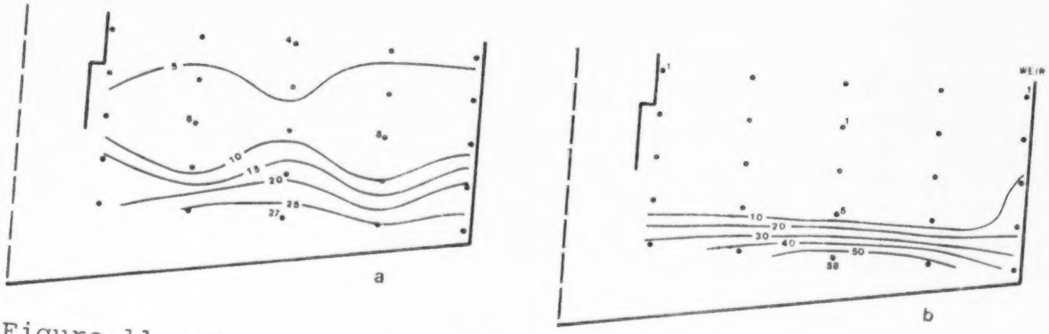


Figure 11. Center feed clarifier with high underflow rate, square-root of TSS distribution (a) and flow pattern in 16 min (b).

Holly Hill, Florida's small rectangular secondaries initially had a high velocity, sludge trough scouring throughflow, shown in Figure 12a. We balanced the inlet ports hydraulically with concrete blocks in the mixed liquor channel and replaced the side-to-side baffle structure with close-in reaction baffles, with the apparent result of a more benign throughflow pattern, Figure 12b. It can be seen here that the blanket was fairly low. However, when the solids rose to somewhere near mid-depth, Figure 13, the cross-sectional area available for horizontal throughflow was reduced, and effluent TSS quality deteriorated seriously.

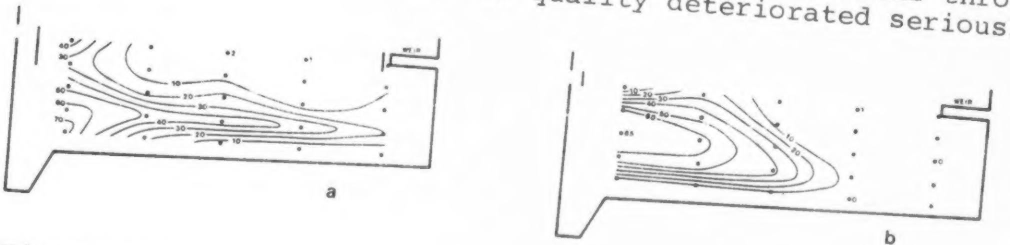


Figure 12. Flow pattern after 15 min in a small rectangular secondary before modification (a), and after (b). Blanket was low in both cases.

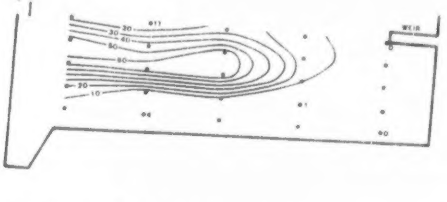


Figure 13. Flow pattern after 15 min in a small rectangular secondary after modification, but with flow constricted by a high blanket.

In general, what seems to happen with a virtual blanket too near the feedwell is a turbulent, high velocity horizontal flow, illustrated in Figure 14. Figure 14 is a composite of numerous samplings of suspended solids in a radial section of a blast furnace scrubber thickener. One such contour plot is shown in Figure 15.

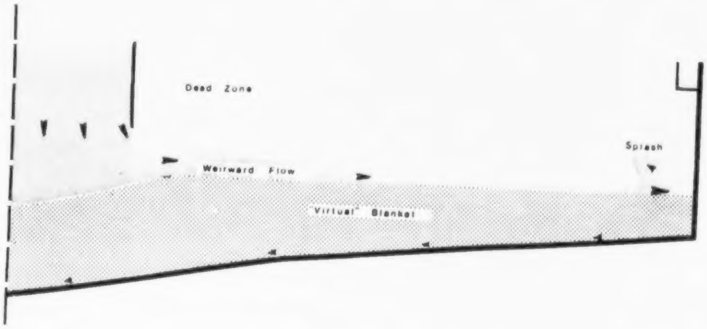


Figure 14. "Average" solids behavior in a center feed blast furnace thickener, high blanket.

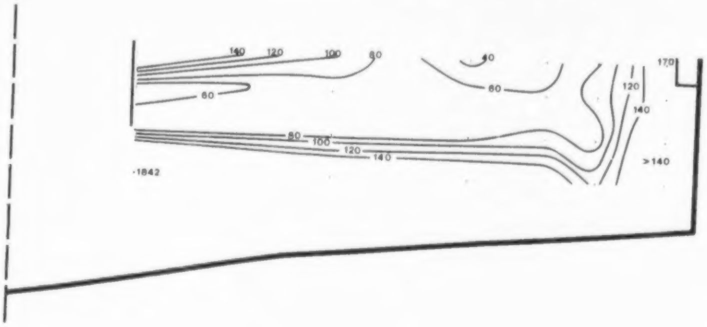


Figure 15. Solids distribution in a blast furnace thickener, high blanket.

These examples were given to illustrate the writer's belief in the importance of controlling blanket depth with respect to inlet baffling. In rare cases of very small flow variability, a blanket which resides above the feedwell depth can result in very low effluent suspended solids, probably through the simple physical means of filtration. In the majority of cases studied, there seems to be a decided advantage in maintaining a blanket as far from the lower extremity of baffling as practicable. (It is recognized that a low blanket may also result in low solids concentrations for wasting.) The worst cases of effluent quality seem to be associated with a medium blanket height, especially when there is little clearance between the compacted sludge and the bottom of a feedwell.

Upgrading Modifications

In every case we have studied so far, the design standard requiring inlets which distribute the flow equally, vertically, has been ignored. The common practice is to encourage immediate downflow of the solids by inlet baffling. There is a widely held belief that the downflow feature of most inlets enhances solids contact and flocculation. Although this may be true, forced downflow also abets development of a density flow which is, in many cases, detrimental to effluent quality. Earlier, it was shown that a bottom-inlet clarifier was improved significantly by encouraging inlet region upflow and breaking up inlet jets. In at least one case, the same effect was achieved by accident.

The Bubble-Curtain Phenomenon--

In a large rectangular secondary in Central Florida, the traveling bridge sludge removal mechanism scraped and lifted sludge only on movement from the effluent end toward the inlet. The result was a resident deposit up to 4% solids concentration on the tank floor near the inlet end. The sludge was septic and producing fine bubbles. The flow pattern which resulted is shown in Figure 16. The shape of the 20 and 25 ppb dye contours at

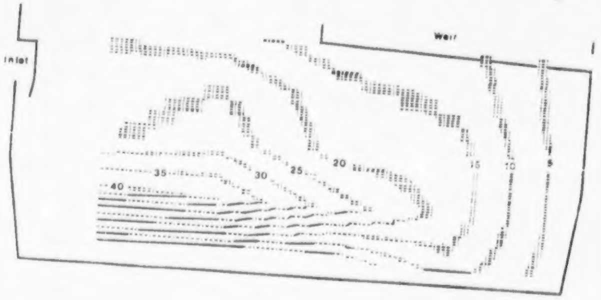


Figure 16. Large rectangular secondary's flow pattern with a methane "bubble curtain" causing vertical mixing near the inlet.

upper left clearly shows the upward movement of fluid at the quarter point, just where bubbling could be seen at the surface. The 5 and 10 ppb contours at the right are strongly suggestive of a near-ideal plug flow condition. The solids distribution near the overflow weirs is shown in Figure 17. With the 10 mg/l TSS contour below the weir, effluent suspended solids were less than 10 mg/l, despite a hydraulic load 33% above design. This is very close to the ideal solids distribution one would expect from Camp's geometric flow model presented earlier. Obviously, no modifications were recommended for these clarifiers.

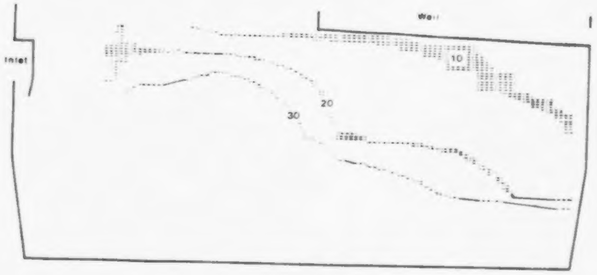


Figure 17. Near-ideal solids distribution in a large rectangular secondary in which vertical mixing occurs near the inlet.

The Stamford Baffle--

Center feedwell, peripheral overflow clarifiers are the most common secondaries in the United States today. The initial flow pattern tests at Stamford, CT, Figure 18a showed a relatively rapid fluid transport in a zone about 12 feet deep, with a sharp upturn at the periphery. Not surprising was the tendency of the solids to follow the flow, Figure 18b. At this time, we felt that the expedient modification would be a peripheral baffle to interrupt the upflow. Figure 19a is the initial flow pattern snapshot after baffle installation. The baffle can be seen at the right, roughly to scale. The flow was turned back toward the center as hoped. The solids were also more favorably distributed, Figure 19b. Later, we recognized the probable cause of upflow in the flow pattern radial section. The test radial section was directly in line with one of four inlet ports, inside the feedwell. A plot of the time variation of solids near the second dot from the top in the right-hand line of sample points in Figure 19 before baffle installation is shown in Figure 20a. The time between peaks was exactly the period of sludge riser pipe passage. After baffle installation, we measured the weir-wall solids plot shown in Figure 20b. The variable solids

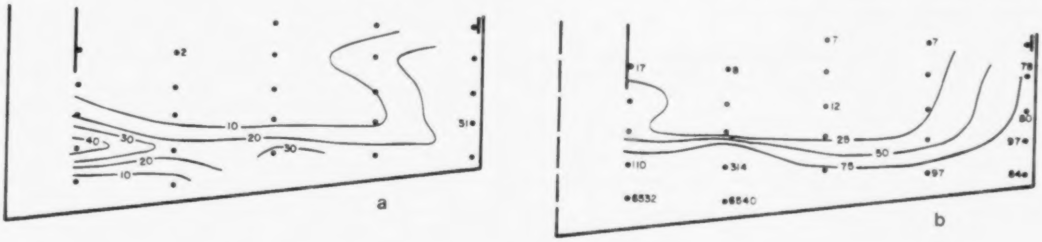


Figure 18. Center feed clarifier flow pattern (a) and solids distribution (b) before baffling, Stamford, CT. (Note: Solids are not square-roots.)

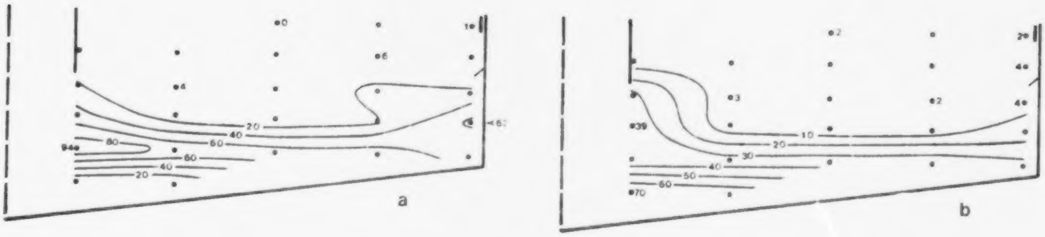

0
1
6
4
20
40
60
80
94
60
40
20
62
a
2
2
4
3
2
4
39
10
20
30
40
50
60
70
b

Figure 19. Center feed clarifier flow pattern (a) and square-root of TSS distribution (b) after peripheral baffle installation.

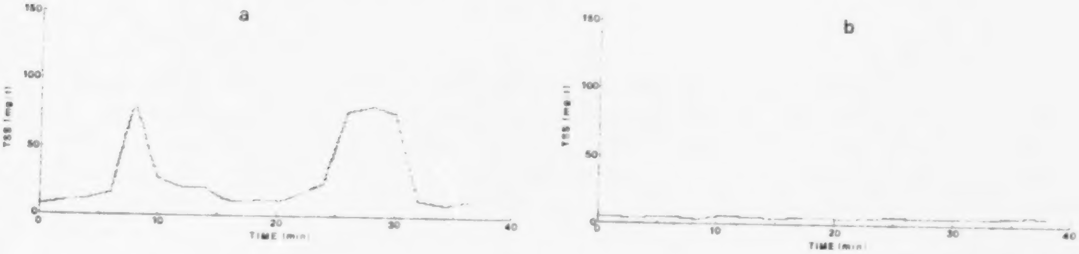


Figure 20. Time-variation of TSS near the weirs at Stamford before baffling (a) and after baffling (b).

phenomenon was almost certainly caused by persistent jets from the inlet ports, periodically interrupted by the rotating sludge header riser pipes. This was confirmed by a solids tracer study, Figure 21. Figure 21a shows the position of the sampling cross-section, at mid-radius (shaded) near the blanket. Figure 21b shows the concentration of sludge dye near the blanket interface, 20 min after dye release in the mixed liquor feed pipe.

The result of the peripheral baffle at Stamford was a 38% reduction in effluent TSS. Material and labor cost was about $3000 for the marine plywood prototype.

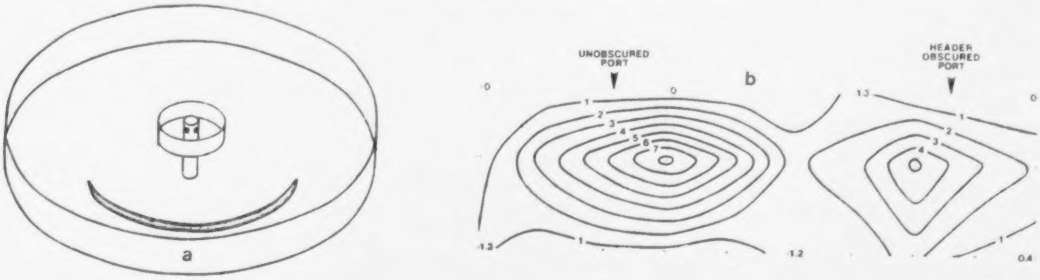

a
UNOBSCURED PORT
HEADER OBSCURED PORT
b
0
0
1.3
0
1
2
3
4
5
6
7
1
2
3
4
1.3
1
1.2
1
0.4

Figure 21. Location of the mid-radius sampling section (a) for the sludge jet test. Sludge dye concentrations are contoured at the right (b).

The Morganton Baffle--

The pre-modification flow pattern in a radial section of Morganton's center feed circular secondary clarifiers is most clearly illustrated in Figure 22. The Morganton pure oxygen

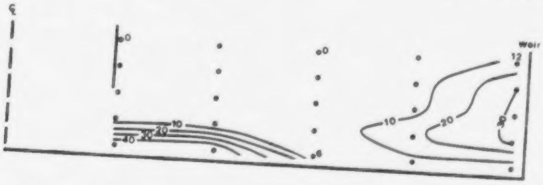


Figure 22. Intense density-flow pattern before baffling, Morganton, NC.

sludge apparently developed a strong density flow which essentially ignored the feedwell. Near the periphery, horizontal flow was less than 1 ft thick. Flow rebounded, or splashed on the peripheral wall. At this plant, we also believed we saw a periodic disturbance in weir-wall solids resulting from sludge header rotation. As an easy first modification, we therefore slowed the header rotation to 56% of the design speed at a cost of $75. The result was an effluent TSS reduction of 10.4%. The second modification at Morganton was a ring baffle/flocculation chamber at mid-radius, extending from the bottom of the tank upward to mid-depth. The baffle was intended to interrupt the forceful density flow which was shown in Figure 22. The flow pattern after baffle installation is shown in Figure 23a. As expected, the throughflow regime was radically altered. Fortunately the solids distribution was also benign, Figure 23b.

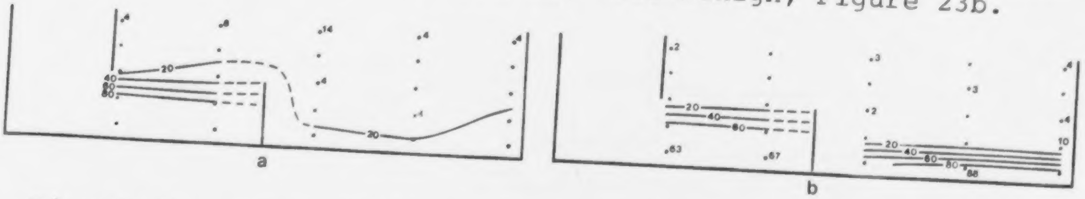


Figure 23. Post-modification flow pattern (a) and square-root of TSS distribution (b), Morganton, NC.

Material cost for this modification, installed by plant operators, was about $3000. An additional 37.5% reduction in effluent TSS was realized. Thus, an overall effluent TSS reduction of nearly 48% was accomplished at Morganton for a material cost of only $3100 per clarifier. At last report, the plant now meets its permit requirements consistently by sending 60% of its flow to the modified clarifier and 40% to a second, parallel unit which has had only the header speed reduction modification.

PITFALLS OF GENERALIZATION

In the 13 clarifiers we've looked at to date, we have yet to meet the same set of effluent degrading circumstances twice. In deciding on clarifier upgrading measures, there is no substitute for careful observation, measurements, and the application of common-sense. The writer is frequently asked to analyze problems by long-distance or on observation of surface phenomena alone. The conclusions reached by this short cut method are almost always wrong. For example, surface observations in a chemical plant's secondaries clearly showed a line of bubbles which followed the single tube sludge header around the tank. The first guess was that the nominal 4 inch clearance of the header above the tank floor was allowing septic sludge to accumulate below, with the header disturbing this layer just enough to skim the methane bubbles. The clarifier had a very low overflow rate, but about 200% underflow rate. The flow pattern, Figure 24, gave an entirely unexpected picture. Instead of diving toward the suction header, the tracer dye avoided the header entirely. The header was completely inactive; all sludge was being returned by way of a missing seal at the center of the tank. The problem was repaired within hours, with a new seal fabricated on-site.

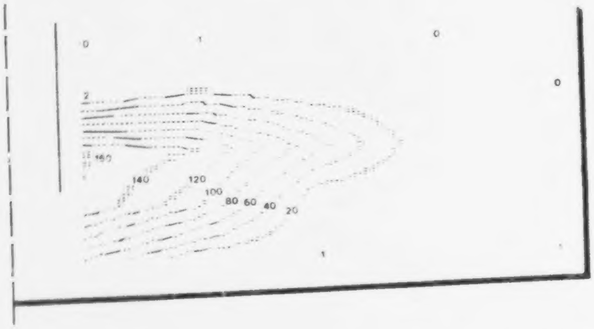


Figure 24. Flow pattern in a center feed circular secondary with an inactive sludge header.

Generalizations must be possible, but this writer does not know how to make them, with the possible exception of those comments already made regarding blanket control. There is no known substitute for the application of a sense of how fluid behaves, backed by the kind of graphic data which has been presented in this paper. Dispersion tests, long used as a measure of hydraulic efficiency, are seen only as back up data; they do not define the reasons for fluid problems. On the other hand, flow pattern tests, although considerably more complicated and costly to perform, can clearly define hydraulic problems in such a way that solutions become obvious.

This nation now has tens of thousands of municipal and industrial clarifiers whose hydraulic characteristics will be found to closely resemble the examples given here. It seems a reasonable goal to upgrade the "bad actors" to achieve more nearly ideal performance before we proceed with major capital expenditures to provide additional hydraulic capacity in the traditional, or design standard dictated sense. If such design standards are to be applied, the design engineer and the regulatory agencies should recognize their shortcomings in light of the real clarifier hydraulic behavior which has been illustrated.

REFERENCES

1. Great Lakes - Upper Mississippi Board of State Sanitary Engineers. Recommended Standards for Sewage Works. Health Education Service, Inc., Albany, New York, 1978. PP 60-1 to 60-3.

2. Camp, T.R. Sedimentation and the Design of Settling Tanks. Transactions Am. Soc. C.E., No. 2285, 1946, pp 895-936.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

PAPER NO. 5

MINIMIZING IMPACT OF SIDE STREAMS ON TOTAL PLANT PERFORMANCE

by

Roy O. Ball, Ph.D., P.E.
Principal

ERM - North Central, Inc.
200 South Prospect Avenue
Park Ridge, Illinois 60068

MINIMIZING IMPACT OF SIDE STREAMS ON TOTAL PLANT PERFORMANCE

Roy O. Ball, Ph.D., P.E.
Principal
ERM-North Central, Inc.

The objective of this conference is to provide technical input to operators and designers of publicly owned treatment plants with the overall goal of improving POTW reliability and performance. The objective of this paper is to provide information on an EPA technical report (soon to be available) with regard to the impact of side streams on main stream performance.[1]

What are side streams? Side streams are those hydraulic flows which result from sludge or waste stream treatment and disposal activities. For example, the supernatant flow from a gravity thickener; the filtrate from a vacuum filter; the supernatant from a secondary digester; and, the liquor from heat treatment operation are all examples of side streams. If these side streams are returned into the main stream treatment process, then they may represent an added load on the facilities. This added load may be purely hydraulic or it may contain significant amounts of pollutants, such as BOD or TSS, or it may contain acidity and alkalinity which might significantly vary the pH in the main stream.

Bob Hegg described many of the conditions that can effect POTW reliability and performance. Although not specifically included in his catalog, side streams are one of the factors that can degrade POTW performance, both in theory and in fact. Must the side streams degrade POTW performance? Based on the analysis described in the Side Streams Report, side streams do not have to degrade POTW performance. The fact that they do, or appear to, is related to the duration of the return event. If the side stream is returned evenly, then it would appear to be a rare situation at which the side streams could degrade main stream performance, even if those side streams had not been included in the original design basis for the facilities.

How do we determine if side streams are a problem? That is one of the major objectives of the side stream's report. The side stream's report is composed of three major sections. The first section has to do with the investigation and evaluation of the plant to answer the question "If there are operational problems, can they be attributed to side streams?" The procedures outlined in this section will enable a definitive answer to that questions. The second section of the report deals with mitigation of the impact of the side streams. The remaining sections of the report deal with handling the effect of the side streams, or mitigating them. The side stream effect can be mitigated in two ways: by changing the source of the side stream, that is the fludge treatment or disposal facility that is generating the flow; and by altering the operation of the main stream process.

In addition to these three major sections, appendices are included which provide information as to the average quality characteristics of side streams as reported in the literature, and also the indexing procedure which was followed to prioritize the side stream matrix; that is which side streams from which facilities being returned to which main stream processes are the most important and worthy of discussion.

The manual provides a user guide with information needed to use the monitoring program, evaluation algorithm, control algorithm, design modification matrix, and design information. Also included in the side stream manual is a detailed example. Three checklists are provided to help the user work through the algorithm. In this paper, it is not possible to display the full scope of the report, but only to indicate the types of material that can be found.

Figure 1 shows the process matrix evaluated.[2] The selection of side stream generator/treatment process pairs was based on an indexing procedure. The procedure included factors for the population served by POTW's with that side stream, the side stream average quality and the cost of treating the side stream pollutants.

Table 1 shows literature references describing side stream quality. It can be seen that little agreement is evident between references. For many of the side streams, the referenced quality differs by three or more orders of magnitude.

Figure 2 shows a summary of the evaluation algorithm process, while Figure 3 indicates where sampling would be required in order to complete the evaluation algorithm.

Figure 3 shows an example of one of the algorithms; in this case, for primary clarification. It can be seen that even this "simple" process requires 33 steps and may refer the analyst to one or more of three design methods for mitigation and one method for operational control.

Figure 4 shows a similar process for activated sludge. Here, 77 steps are required, up to 13 design mitigation methods may be recommended, and up to 25 operation methods may be recommended.

Figure 5 shows an example of an operational methods algorithm for primary clarifiers, and Figure 6 shows a corresponding algorighm for activated sludge. In each case, once all the main stream changes that can be made have been made, the user is referred to side stream operational control algorithms; an example of which (in this case for gravity thickeners) is shown in Figure 7.

After all operational methods have been implemented, some design modifications are described in the manual. Most of the modifications deal with increasing the time span over which the side stream is returned.

In summary, the side streams manual represents a flexible and powerful tool to diagnose and mitigate the impact of side streams at POTW's.

---

[1] Presentation based on a study and report by Roy F. Weston, Inc. for EPA MERL.

[2] The Figures and Tables used in this paper duplicate those used in the Side Streams Report.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

Sidestream Generator	Treatment Process			
	Primary (P)	Activated Sludge (AS)	Trickling Filter (TF)	Rotating Biological Contactor (RBC)
Gravity Thickener (GT)	○	●	●	●
Dissolved Air Flotation (DAF)	○	●	●	●
Anaerobic Digestion (AnD)	●	●	●	●
Aerobic Digestion (AeD)	○	●	●	●
Vacuum Filter (VF)	●	●	○	○
Centrifuge (C)	●	●	●	●
Belt Filter Press (BF)	●	●	●	●
Sand Drying Bed (SB)	●	●	●	●
Lagoon (LA)	○	●	●	●
Heat Treatment (HT)	●	●	●	●
Wet Air Oxidation (WAO)	●	●	●	●
Pressure Filter (Filter Press, FP)	●	●	●	●
Purifax(PX)	●	●	●	●

○ No evaluation required
● Evaluation required

FIGURE 1. PROCESS MATRIX

Table 1

Summary of Literature Review

Sidestream Generator	Abbreviation	Numbers In Use	Solids Retention %	References	BOD$_5$ mg/L	References	SS mg/L	References
Gravity Thickening	GT	940	80-95	3,42,49,59,75	100-400	35,49,72,75	98-2,500	3,7,25,35,42,49, 59,61,64,72,74,75, 77,81,108,118,120, 121
Dissolved Air Flotation	DAF	314	70-99.1	4,39,40,42,48,55, 59,60,64,75,121	50-3,950	72,75	20-2,440	4,25,39,40,42,49, 55,59,60,64,67,72, 75,76,87,94,95,100, 104,108,114,121
Anaerobic Digestion	AnD	6,796			2-11,014	13,14,29,49,55, 56,57,72,75,76, 87,995,100,108, 121	100-32,400	12,13,14,21,49,55, 56,57,62,72,75,76, 87,94,95,100,104, 108,114,121
Aerobic Digestion	AeD	4,750			5-6,350	1,21,52,55,75,121	10-41,800	1,4,52,55,64,75, 121
Vacuum Filtration	VF	1,912	80-99.5	33,65,70,75,94, 96,120	10-10,000	14,55,75,108,122	160-20,000	4,14,25,26,33,36, 42,47,55,65,70,72, 75,80,87,94,96,108, 114,120,121
Centrifugation	C	368	30-98	3,4,6,21,33,40, 42,43,55,72,75, 83,87,94,96,98, 104,108,115,121 122	173-10,000	49,75,87,122	100-20,000	2,3,4,20,21,25,33, 40,42,49,55,72,75, 83,87,94,96,98,108, 114,115,120,211,122
Belt Filter Press	BF	132	22-99.8	4,33,36,94,117, 122	46-146	122	30-3,400	4,9,16,33,36,55,94, 96,117,122
Sand Drying Beds	SB	10,939	85-100	33,108	6-6,000	14,29,55,72,108	20-800	14,33,54,72,104,112
Lagoons	LA	797			150	49	71	49
Heat Treatment	HT	170	90-99+	49	1,600-15,000	47,14,29,30,32,37, 42,48,49,50,55,56, 72,75,108,121	50-11,400	14,25,32,42,48,49,50, 55,72,75,87,103,108, 112
Wet Air Oxidation	WAO	13	90-99+	49	3,000-10,000	14,29,32,37,42,51, 55,49,72,75,108,121	20-500	14,32,42,49,55,75,99
Pressure Filter	FP	157	96-100	18,33,75,96	1,000-6,500	25	100-1,926	4,25,26,33,42,55,75, 96,121
Purifax	PX	69			100-350	14,16,108	50-150	14,16,112,121

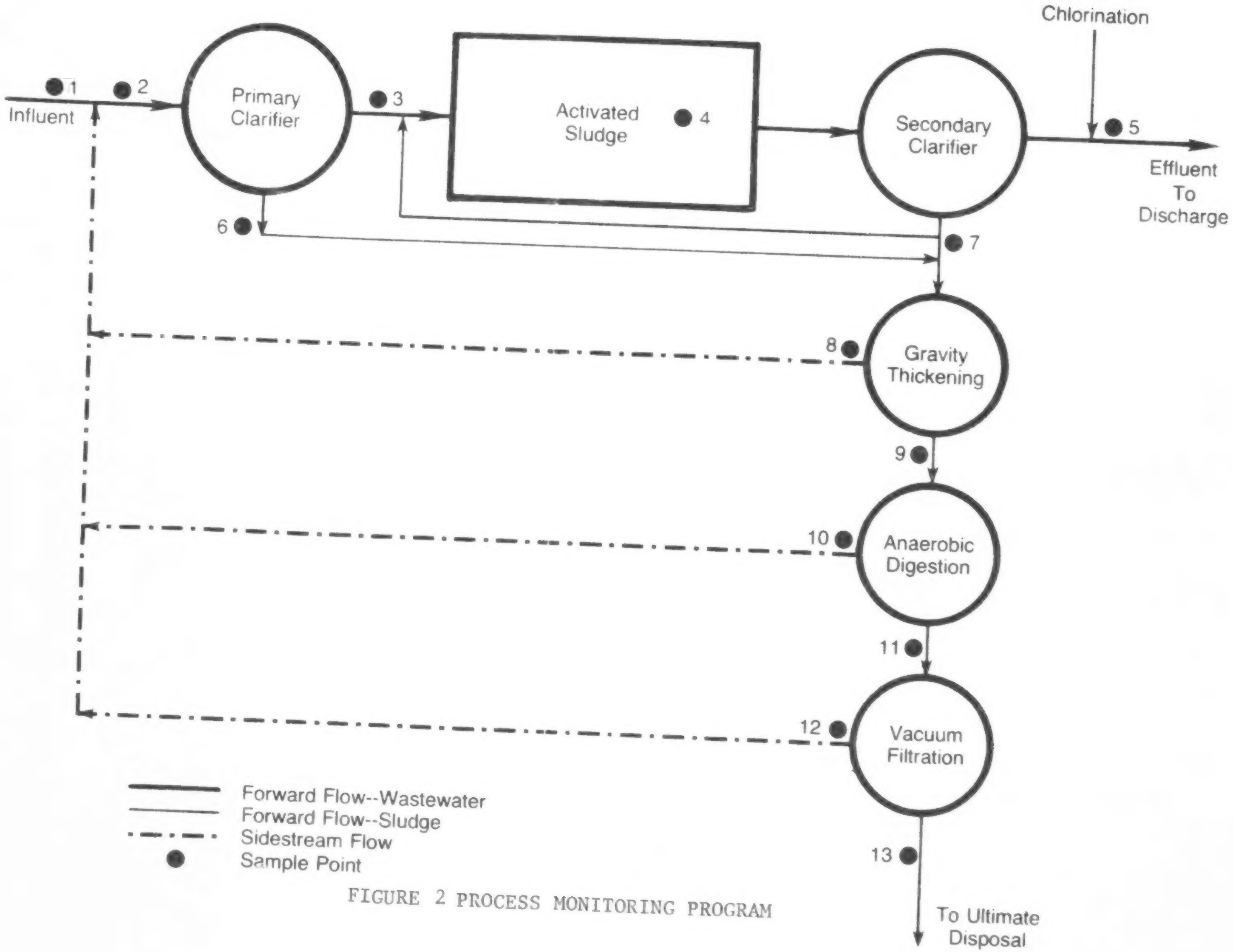

Influent
1
2
Primary Clarifier
3
Activated Sludge
4
Secondary Clarifier
Chlorination
5
Effluent To Discharge
6
7
8
Gravity Thickening
9
10
Anaerobic Digestion
11
12
Vacuum Filtration
13
To Ultimate Disposal
Forward Flow--Wastewater
Forward Flow--Sludge
Sidestream Flow
Sample Point

FIGURE 2 PROCESS MONITORING PROGRAM

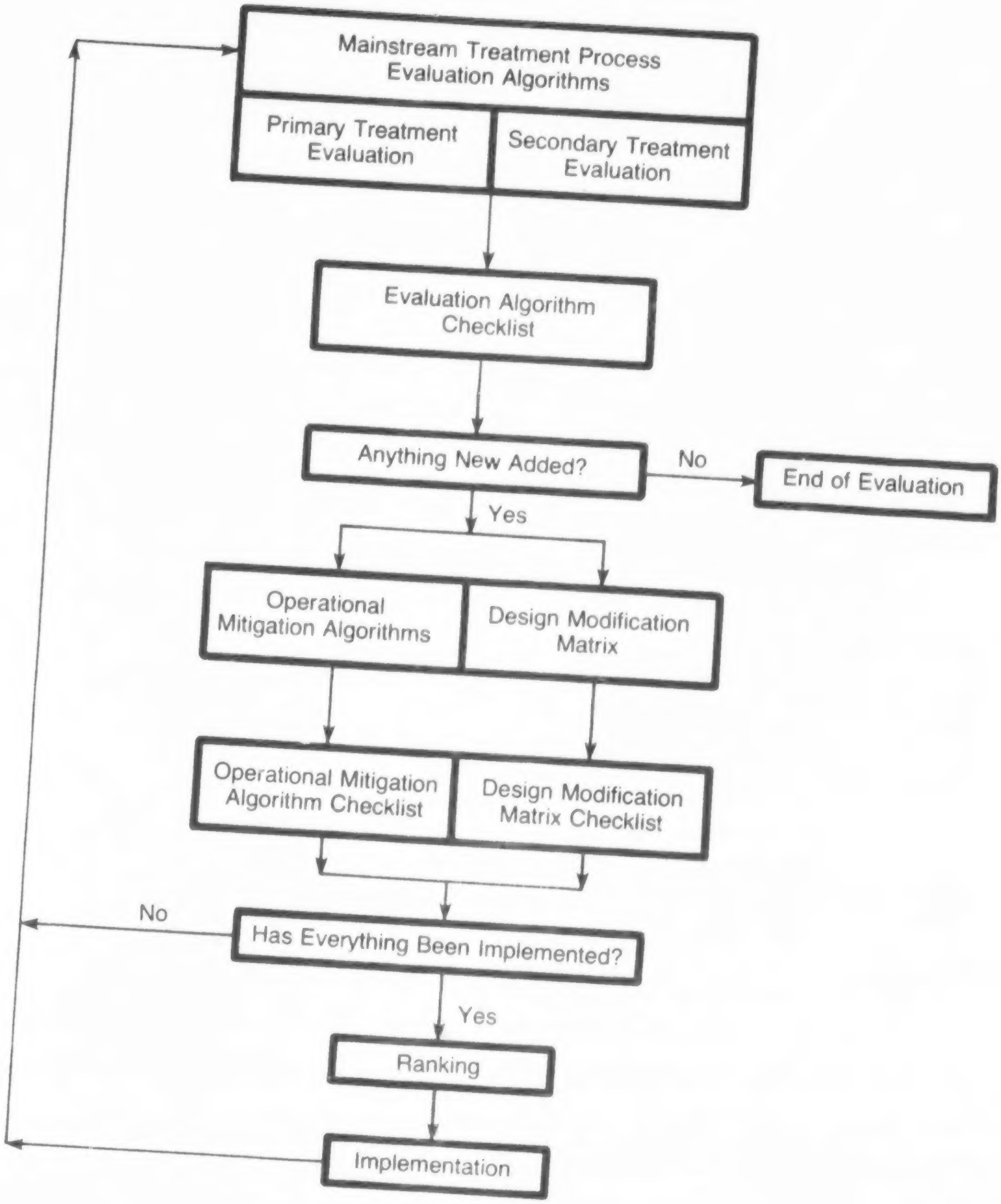

Mainstream Treatment Process Evaluation Algorithms
Primary Treatment Evaluation
Secondary Treatment Evaluation
Evaluation Algorithm Checklist
Anything New Added?
No
End of Evaluation
Yes
Operational Mitigation Algorithms
Design Modification Matrix
Operational Mitigation Algorithm Checklist
Design Modification Matrix Checklist
No
Has Everything Been Implemented?
Yes
Ranking
Implementation

FIGURE 3. SUMMARY OF EVALUATION PROCESS

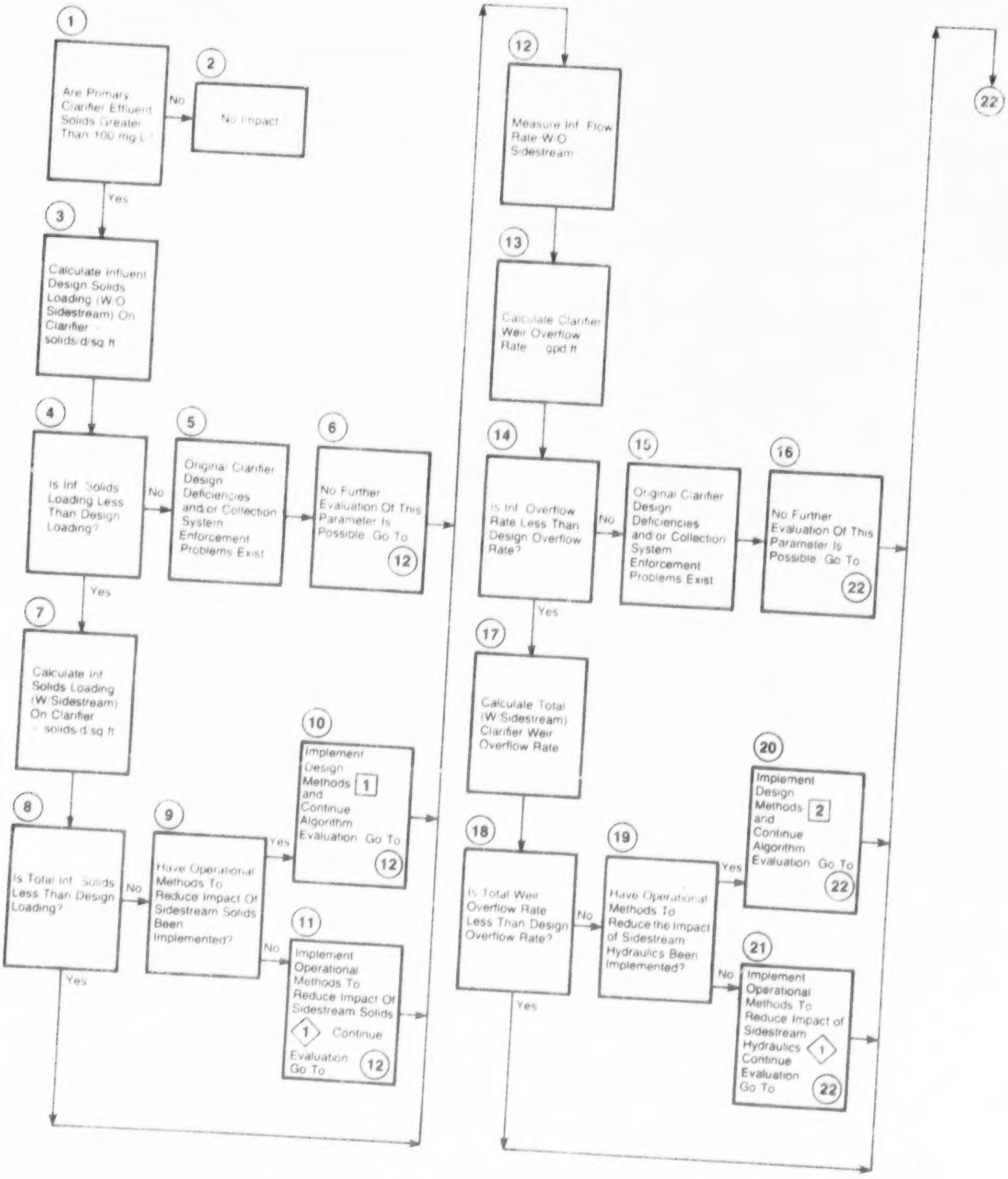

1
Are Primary Clarifier Effluent Solids Greater Than 100 mg/L?
No
2
No Impact
Yes
3
Calculate Influent Design Solids Loading (W/O Sidestream) On Clarifier = solids/d/sq ft
4
Is Inf. Solids Loading Less Than Design Loading?
No
5
Original Clarifier Design Deficiencies and/or Collection System Enforcement Problems Exist
6
No Further Evaluation Of This Parameter Is Possible. Go To 12
Yes
7
Calculate Inf Solids Loading (W/Sidestream) On Clarifier = solids/d/sq ft
8
Is Total Inf. Solids Less Than Design Loading?
No
9
Have Operational Methods To Reduce Impact Of Sidestream Solids Been Implemented?
Yes
10
Implement Design Methods 1 and Continue Algorithm Evaluation. Go To 12
No
11
Implement Operational Methods To Reduce Impact Of Sidestream Solids 1 Continue Evaluation Go To 12
Yes
12
Measure Inf. Flow Rate W/O Sidestream
13
Calculate Clarifier Weir Overflow Rate = gpd/ft
14
Is Inf. Overflow Rate Less Than Design Overflow Rate?
No
15
Original Clarifier Design Deficiencies and/or Collection System Enforcement Problems Exist
16
No Further Evaluation Of This Parameter Is Possible. Go To 22
Yes
17
Calculate Total (W/Sidestream) Clarifier Weir Overflow Rate
18
Is Total Weir Overflow Rate Less Than Design Overflow Rate?
No
19
Have Operational Methods To Reduce the Impact of Sidestream Hydraulics Been Implemented?
Yes
20
Implement Design Methods 2 and Continue Algorithm Evaluation. Go To 22
No
21
Implement Operational Methods To Reduce Impact of Sidestream Hydraulics 1 Continue Evaluation Go To 22
Yes
22

FIGURE 4. EVALUATION OF SIDESTREAM IMPACT ON PRIMARY CLARIFICATION

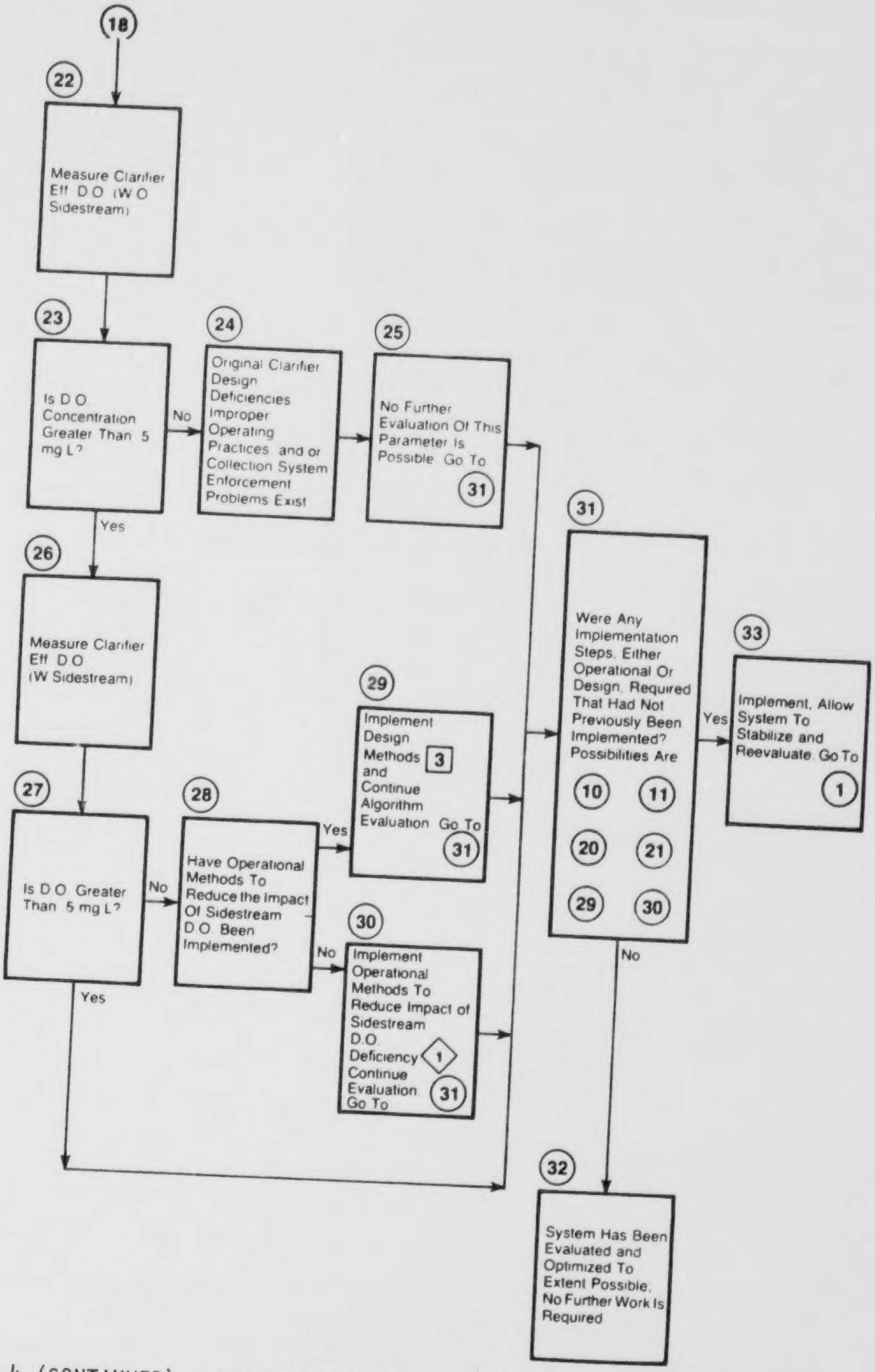

18
22
Measure Clarifier Eff D O (W O Sidestream)
23
Is D O Concentration Greater Than 5 mg L?
No
24
Original Clarifier Design Deficiencies Improper Operating Practices and or Collection System Enforcement Problems Exist
25
No Further Evaluation Of This Parameter Is Possible Go To 31
Yes
26
Measure Clarifier Eff D O (W Sidestream)
27
Is D O Greater Than 5 mg L?
No
28
Have Operational Methods To Reduce the Impact Of Sidestream D O Been Implemented?
Yes
29
Implement Design Methods 3 and Continue Algorithm Evaluation Go To 31
No
30
Implement Operational Methods To Reduce Impact of Sidestream D.O. Deficiency 1 Continue Evaluation Go To 31
Yes
31
Were Any Implementation Steps, Either Operational Or Design, Required That Had Not Previously Been Implemented? Possibilities Are
10
11
20
21
29
30
Yes
33
Implement, Allow System To Stabilize and Reevaluate. Go To 1
No
32
System Has Been Evaluated and Optimized To Extent Possible. No Further Work Is Required

FIGURE 4 (CONTINUED). EVALUATION OF SIDESTREAM IMPACT ON PRIMARY CLARIFICATION

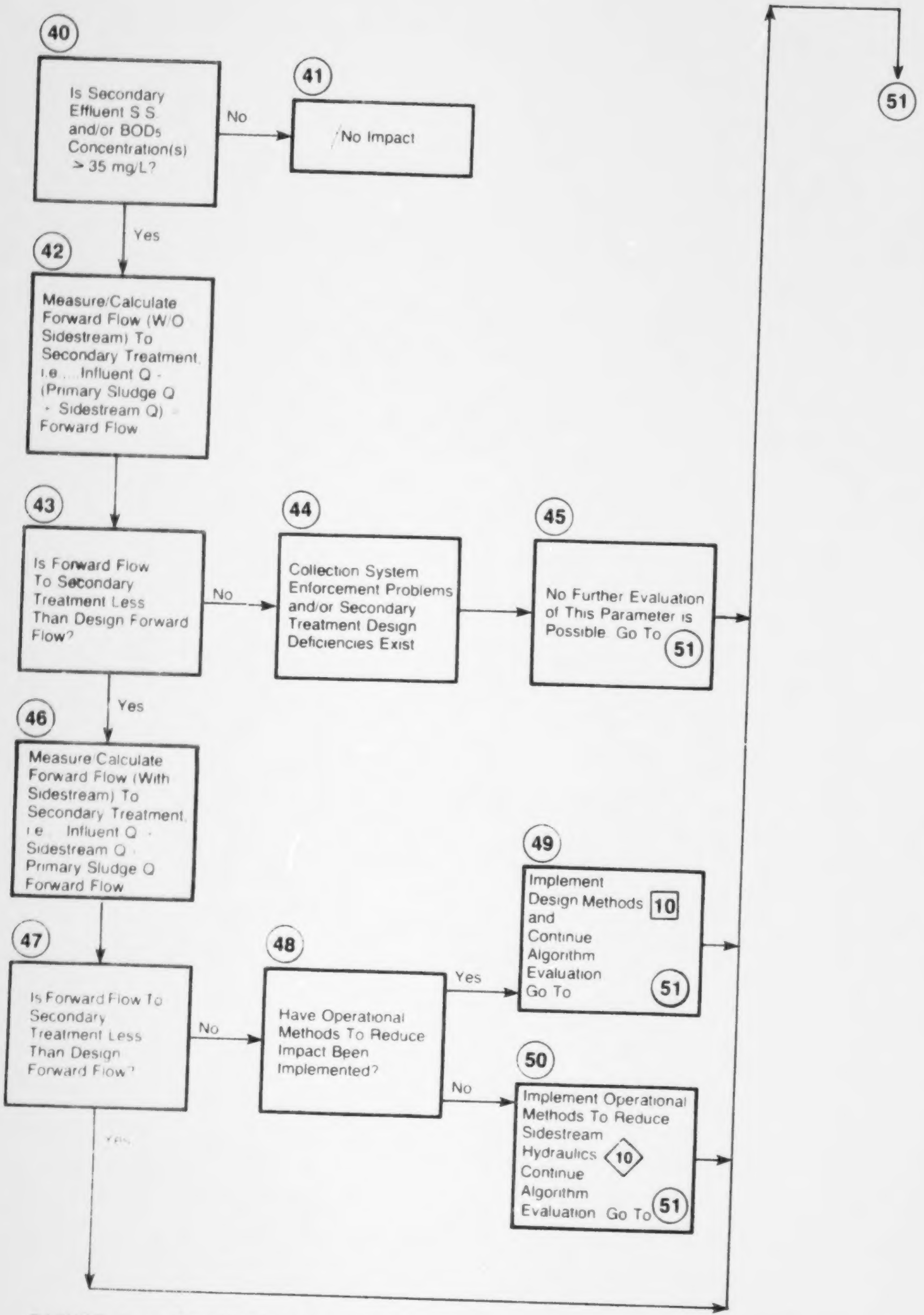

40
Is Secondary Effluent S.S. and/or BOD5 Concentration(s) > 35 mg/L?
No
41
No Impact
Yes
42
Measure/Calculate Forward Flow (W/O Sidestream) To Secondary Treatment, i.e., Influent Q - (Primary Sludge Q + Sidestream Q) = Forward Flow
43
Is Forward Flow To Secondary Treatment Less Than Design Forward Flow?
No
44
Collection System Enforcement Problems and/or Secondary Treatment Design Deficiencies Exist
45
No Further Evaluation of This Parameter is Possible. Go To 51
Yes
46
Measure/Calculate Forward Flow (With Sidestream) To Secondary Treatment, i.e., Influent Q + Sidestream Q - Primary Sludge Q = Forward Flow
47
Is Forward Flow To Secondary Treatment Less Than Design Forward Flow?
No
48
Have Operational Methods To Reduce Impact Been Implemented?
Yes
49
Implement Design Methods 10 and Continue Algorithm Evaluation Go To 51
No
50
Implement Operational Methods To Reduce Sidestream Hydraulics 10 Continue Algorithm Evaluation Go To 51
Yes
51

FIGURE 5. EVALUATION OF SIDESTREAM IMPACT ON ACTIVATED SLUDGE

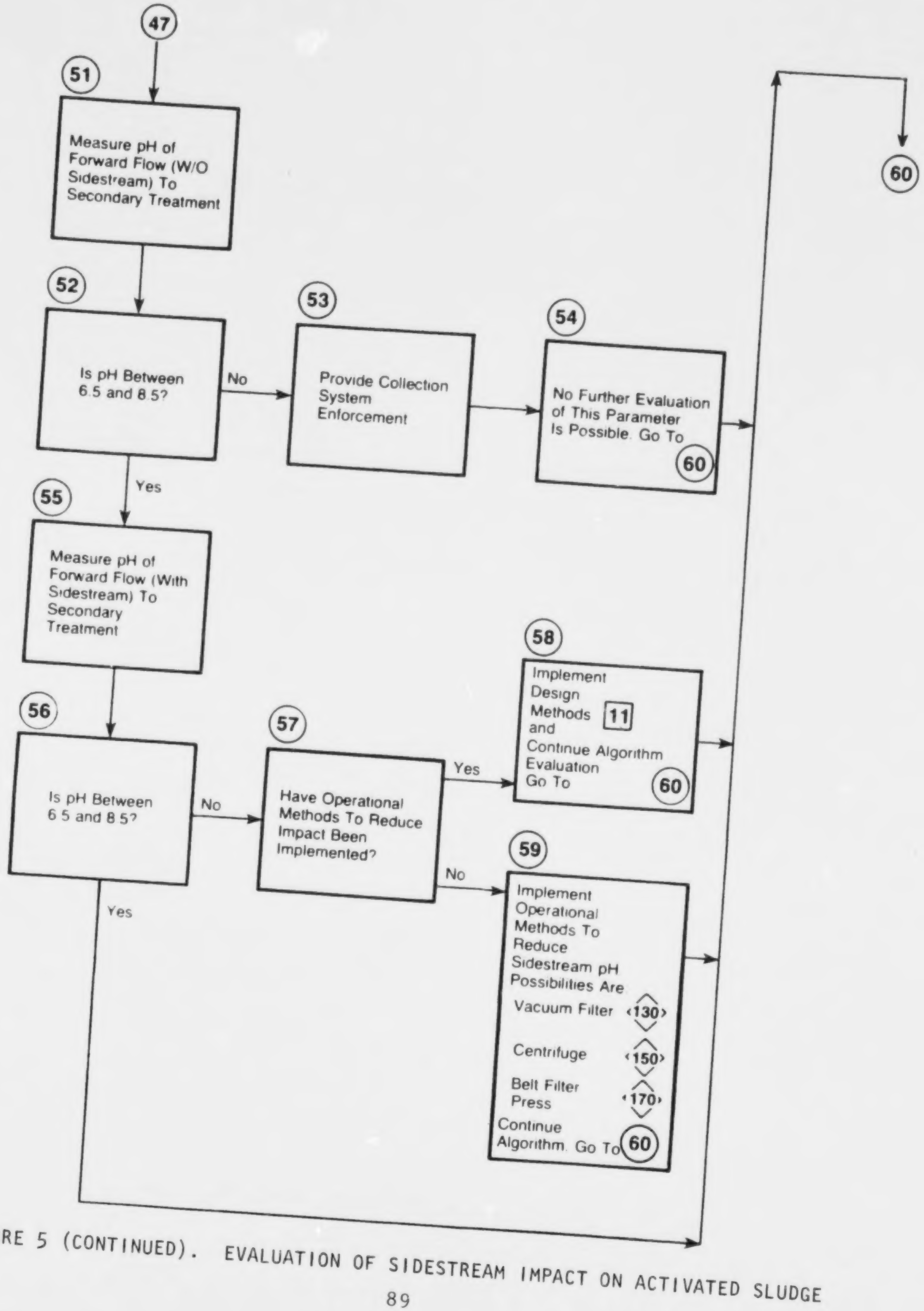

47
51
Measure pH of Forward Flow (W/O Sidestream) To Secondary Treatment
52
Is pH Between 6.5 and 8.5?
No
53
Provide Collection System Enforcement
54
No Further Evaluation of This Parameter Is Possible. Go To 60
Yes
55
Measure pH of Forward Flow (With Sidestream) To Secondary Treatment
56
Is pH Between 6.5 and 8.5?
No
57
Have Operational Methods To Reduce Impact Been Implemented?
Yes
58
Implement Design Methods 11 and Continue Algorithm Evaluation Go To 60
No
59
Implement Operational Methods To Reduce Sidestream pH Possibilities Are
Vacuum Filter 130
Centrifuge 150
Belt Filter Press 170
Continue Algorithm. Go To 60
Yes
60

FIGURE 5 (CONTINUED). EVALUATION OF SIDESTREAM IMPACT ON ACTIVATED SLUDGE

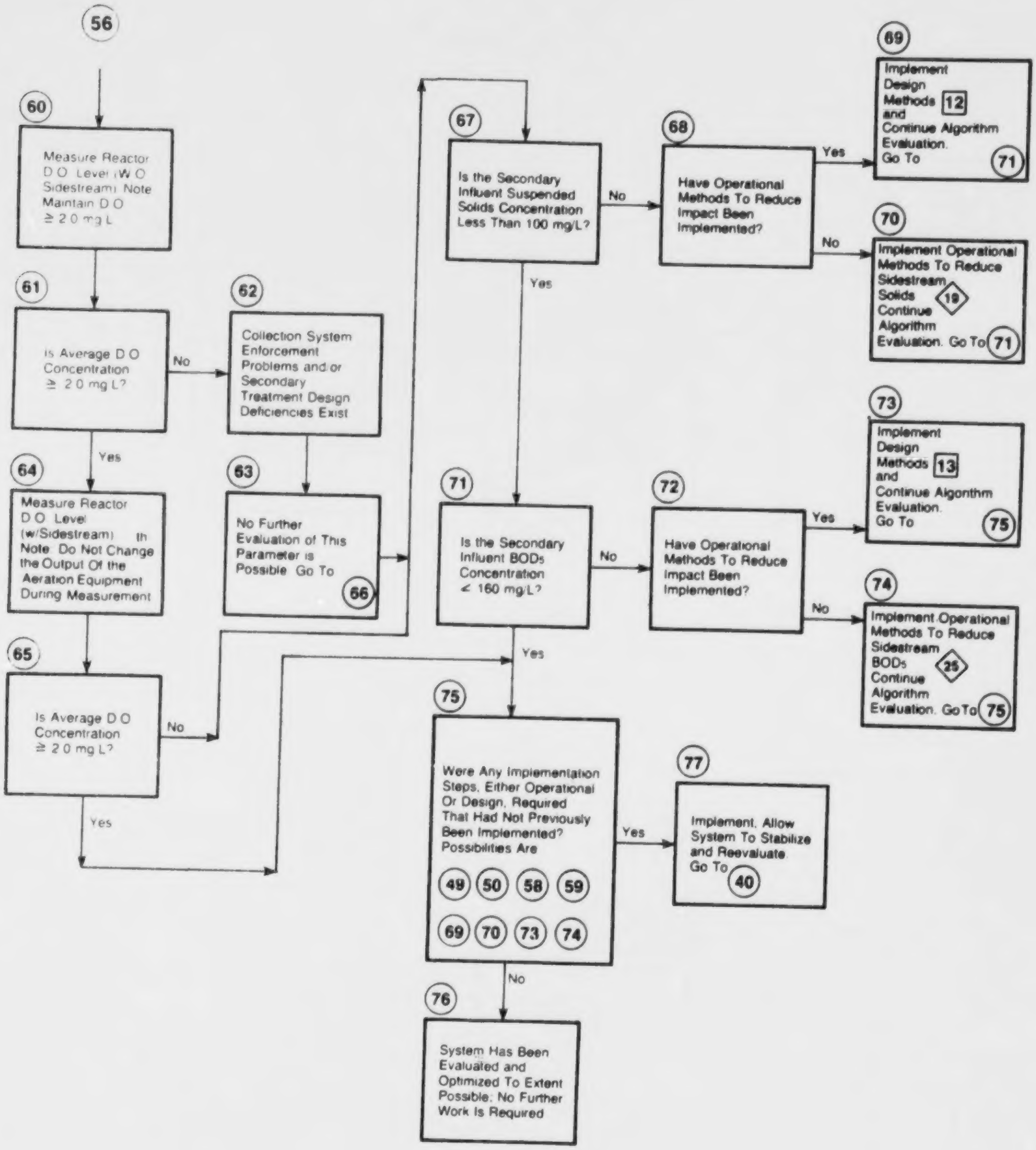

56
60
Measure Reactor D O Level (W O Sidestream) Note Maintain D O ≥ 2 0 mg L
61
Is Average D O Concentration ≥ 2 0 mg L?
No
62
Collection System Enforcement Problems and/or Secondary Treatment Design Deficiencies Exist
Yes
64
Measure Reactor D O Level (w/Sidestream) th Note Do Not Change the Output Of the Aeration Equipment During Measurement
63
No Further Evaluation of This Parameter is Possible Go To 56
65
Is Average D O Concentration ≥ 2 0 mg L?
No
Yes
67
Is the Secondary Influent Suspended Solids Concentration Less Than 100 mg/L?
No
68
Have Operational Methods To Reduce Impact Been Implemented?
Yes
69
Implement Design Methods 12 and Continue Algorithm Evaluation. Go To 71
No
70
Implement Operational Methods To Reduce Sidestream Solids 19 Continue Algorithm Evaluation. Go To 71
Yes
71
Is the Secondary Influent BOD5 Concentration < 160 mg/L?
No
72
Have Operational Methods To Reduce Impact Been Implemented?
Yes
73
Implement Design Methods 13 and Continue Algorithm Evaluation. Go To 75
No
74
Implement Operational Methods To Reduce Sidestream BOD5 25 Continue Algorithm Evaluation. Go To 75
Yes
75
Were Any Implementation Steps, Either Operational Or Design, Required That Had Not Previously Been Implemented? Possibilities Are
49 50 58 59
69 70 73 74
Yes
77
Implement, Allow System To Stabilize and Reevaluate. Go To 40
No
76
System Has Been Evaluated and Optimized To Extent Possible; No Further Work Is Required

FIGURE 5 (CONTINUED). EVALUATION OF SIDESTREAM IMPACT ON ACTIVATED SLUDGE

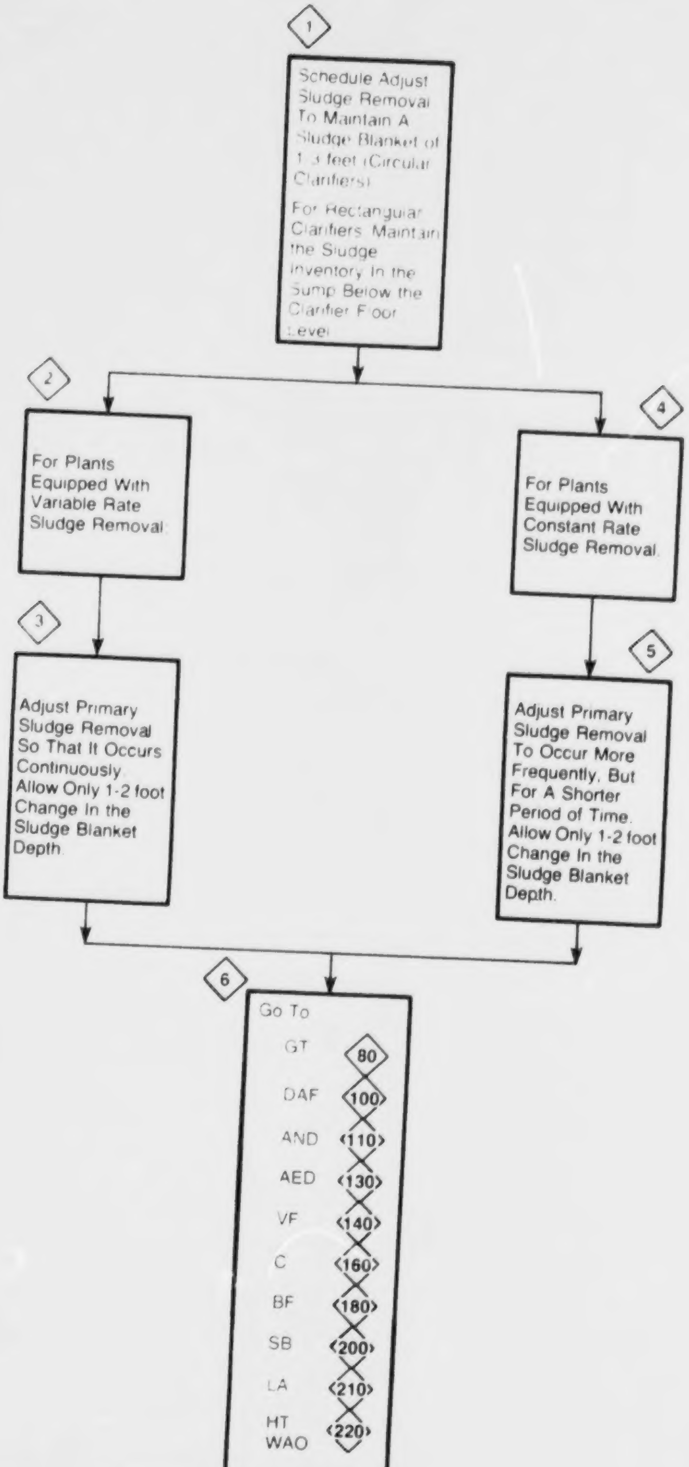

1
Schedule Adjust Sludge Removal To Maintain A Sludge Blanket of 1-3 feet (Circular Clarifiers)
For Rectangular Clarifiers Maintain the Sludge Inventory In the Sump Below the Clarifier Floor Level.
2
For Plants Equipped With Variable Rate Sludge Removal.
4
For Plants Equipped With Constant Rate Sludge Removal.
3
Adjust Primary Sludge Removal So That It Occurs Continuously. Allow Only 1-2 foot Change In the Sludge Blanket Depth.
5
Adjust Primary Sludge Removal To Occur More Frequently, But For A Shorter Period of Time. Allow Only 1-2 foot Change In the Sludge Blanket Depth.
6
Go To
GT 80
DAF 100
AND 110
AED 130
VF 140
C 160
BF 180
SB 200
LA 210
HT WAO 220

FIGURE 6. OPERATIONAL METHODS TO REDUCE THE IMPACT OF SIDESTREAMS ON PRIMARY CLARIFIERS

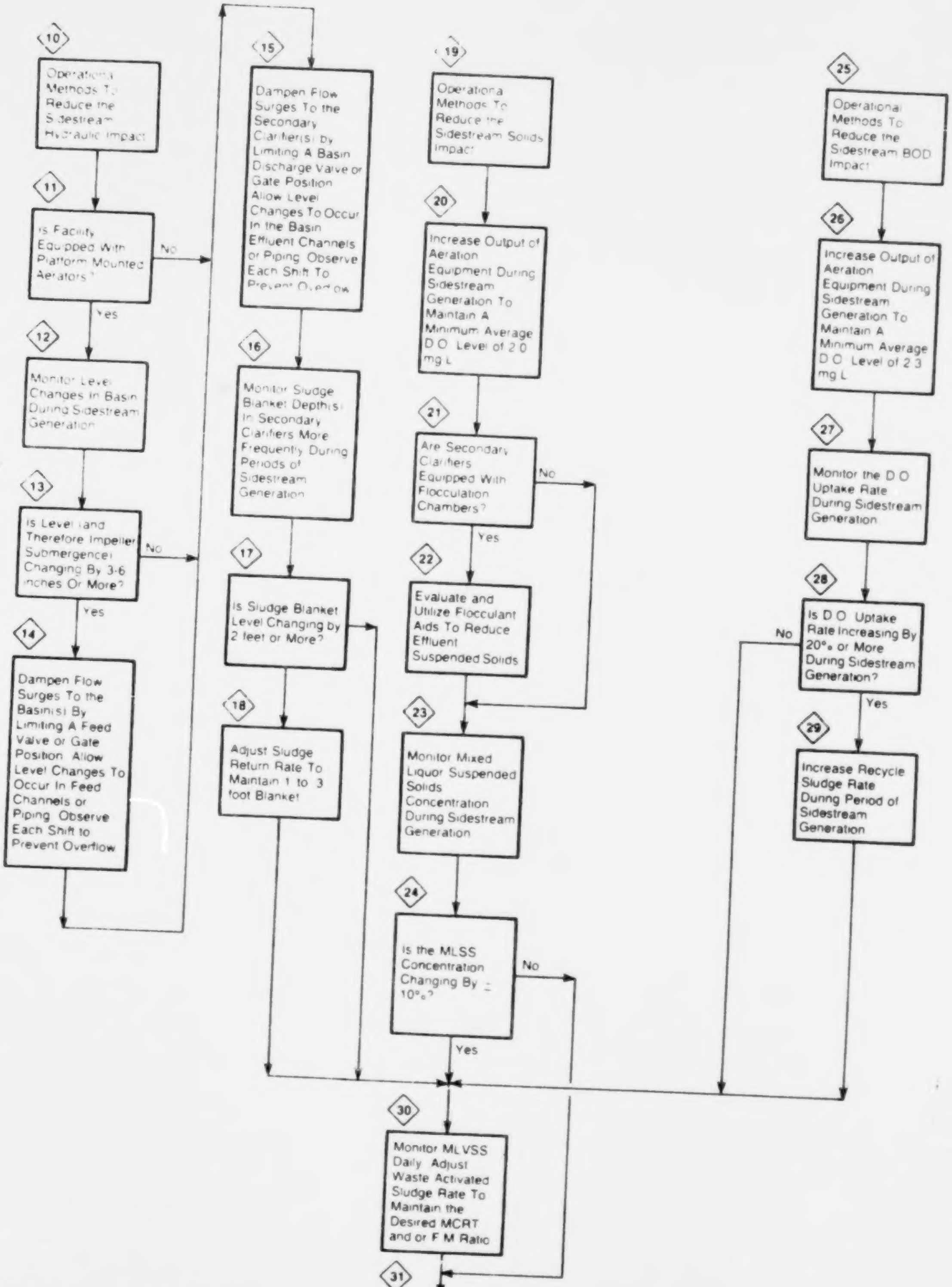

10
Operational Methods To Reduce the Sidestream Hydraulic Impact
11
Is Facility Equipped With Platform Mounted Aerators?
No
Yes
12
Monitor Level Changes in Basin During Sidestream Generation
13
Is Level (and Therefore Impeller Submergence) Changing By 3-6 inches Or More?
No
Yes
14
Dampen Flow Surges To the Basin(s) By Limiting A Feed Valve or Gate Position. Allow Level Changes To Occur In Feed Channels or Piping. Observe Each Shift to Prevent Overflow
15
Dampen Flow Surges To the Secondary Clarifier(s) by Limiting A Basin Discharge Valve or Gate Position. Allow Level Changes To Occur In the Basin Effluent Channels or Piping. Observe Each Shift To Prevent Overflow
16
Monitor Sludge Blanket Depth(s) In Secondary Clarifiers More Frequently During Periods of Sidestream Generation
17
Is Sludge Blanket Level Changing by 2 feet or More?
18
Adjust Sludge Return Rate To Maintain 1 to 3 foot Blanket
19
Operational Methods To Reduce the Sidestream Solids Impact
20
Increase Output of Aeration Equipment During Sidestream Generation To Maintain A Minimum Average D.O. Level of 2.0 mg/L
21
Are Secondary Clarifiers Equipped With Flocculation Chambers?
No
Yes
22
Evaluate and Utilize Flocculant Aids To Reduce Effluent Suspended Solids
23
Monitor Mixed Liquor Suspended Solids Concentration During Sidestream Generation
24
Is the MLSS Concentration Changing By ± 10%?
No
Yes
25
Operational Methods To Reduce the Sidestream BOD Impact
26
Increase Output of Aeration Equipment During Sidestream Generation To Maintain A Minimum Average D.O. Level of 2.3 mg/L
27
Monitor the D.O. Uptake Rate During Sidestream Generation
28
Is D.O. Uptake Rate Increasing By 20% or More During Sidestream Generation?
No
Yes
29
Increase Recycle Sludge Rate During Period of Sidestream Generation
30
Monitor MLVSS Daily. Adjust Waste Activated Sludge Rate To Maintain the Desired MCRT and/or F/M Ratio
31

FIGURE 7. OPERATIONAL METHODS TO REDUCE SIDESTREAM IMPACTS ON A.S.

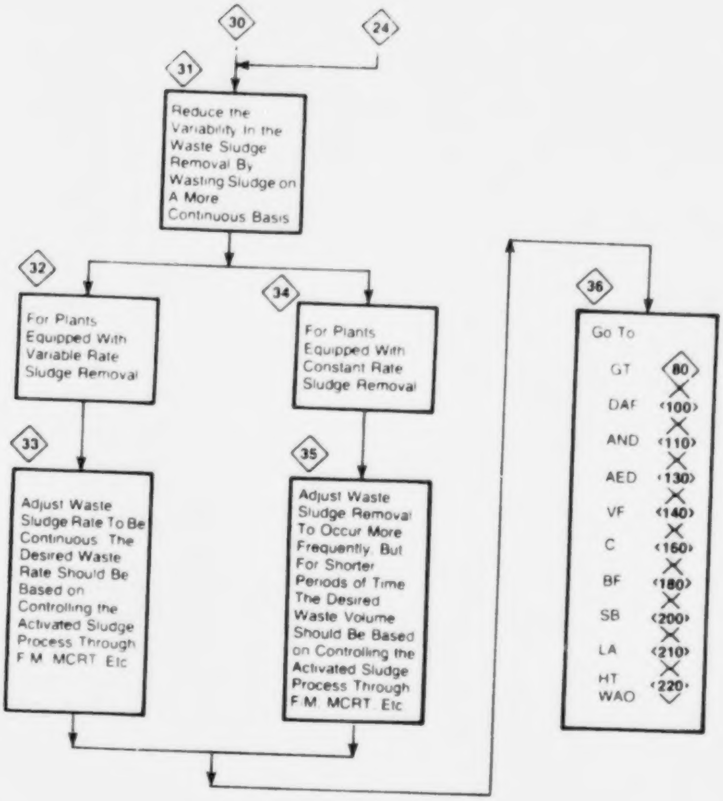
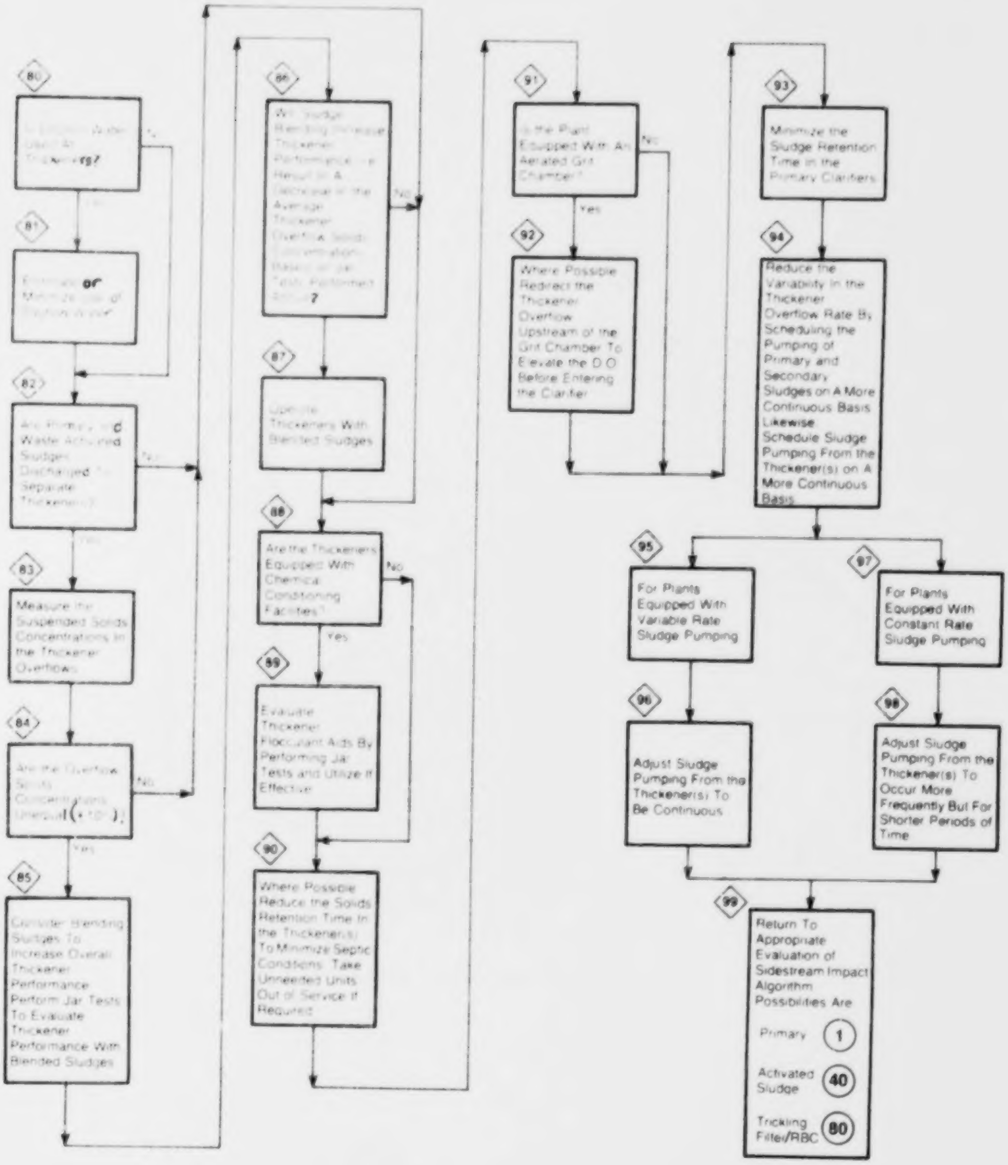

30
24
31
Reduce the Variability In the Waste Sludge Removal By Wasting Sludge on A More Continuous Basis
32
For Plants Equipped With Variable Rate Sludge Removal
34
For Plants Equipped With Constant Rate Sludge Removal
33
Adjust Waste Sludge Rate To Be Continuous. The Desired Waste Rate Should Be Based on Controlling the Activated Sludge Process Through F:M, MCRT, Etc.
35
Adjust Waste Sludge Removal To Occur More Frequently, But For Shorter Periods of Time. The Desired Waste Volume Should Be Based on Controlling the Activated Sludge Process Through F:M, MCRT, Etc.
36
Go To
GT 80
DAF 100
AND 110
AED 130
VF 140
C 160
BF 180
SB 200
LA 210
HT WAO 220

FIGURE 7 (CONTINUED). OPERATIONAL METHODS TO REDUCE SIDESTREAM IMPACTS ON A.S.



80
Is Dilution Water Used At Thickeners?
No
Yes
81
Eliminate or Minimize Use of Dilution Water
82
Are Primary and Waste Activated Sludges Discharged To Separate Thickeners?
No
Yes
83
Measure the Suspended Solids Concentrations In the Thickener Overflows
84
Are the Overflow Solids Concentrations Unequal (± 10%)?
No
Yes
85
Consider Blending Sludges To Increase Overall Thickener Performance Perform Jar Tests To Evaluate Thickener Performance With Blended Sludges
86
Will Sludge Blending Increase Thickener Performance (i.e. Result in A Decrease in the Average Thickener Overflow Solids Concentration) Based on Jar Tests Performed Above?
No
87
Operate Thickeners With Blended Sludges
88
Are the Thickeners Equipped With Chemical Conditioning Facilities?
No
Yes
89
Evaluate Thickener Flocculant Aids By Performing Jar Tests and Utilize If Effective
90
Where Possible Reduce the Solids Retention Time In the Thickener(s) To Minimize Septic Conditions. Take Unneeded Units Out of Service If Required
91
Is the Plant Equipped With An Aerated Grit Chamber?
No
Yes
92
Where Possible Redirect the Thickener Overflow Upstream of the Grit Chamber To Elevate the D.O. Before Entering the Clarifier
93
Minimize the Sludge Retention Time in the Primary Clarifiers
94
Reduce the Variability in the Thickener Overflow Rate By Scheduling the Pumping of Primary and Secondary Sludges on A More Continuous Basis. Likewise Schedule Sludge Pumping From the Thickener(s) on A More Continuous Basis
95
For Plants Equipped With Variable Rate Sludge Pumping
96
Adjust Sludge Pumping From the Thickener(s) To Be Continuous
97
For Plants Equipped With Constant Rate Sludge Pumping
98
Adjust Sludge Pumping From the Thickener(s) To Occur More Frequently But For Shorter Periods of Time
99
Return To Appropriate Evaluation of Sidestream Impact Algorithm Possibilities Are
Primary
1
Activated Sludge
40
Trickling Filter/RBC
80

FIGURE 8. OPERATIONAL METHODS TO REDUCE THE IMPACT OF GRAVITY THICKENERS

PAPER NO. 6

COMPOSITE CORRECTION PROGRAM-
CONCEPTS AND DEMONSTRATION

by

Bob A. Hegg
Vice President Plant Operations Division

M & I, Inc., Consulting Engineers
4710 South College Avenue
Fort Collins, Colorado 80525

COMPOSITE CORRECTION PROGRAM - CONCEPTS AND DEMONSTRATION

Bob A. Hegg, Vice President Plant Operations Division
M & I, Inc., Consulting Engineers

INTRODUCTION

Non-compliance of wastewater treatment facilities has been the focus of numerous studies, seminars, and published articles for a number of years. Several of these studies were funded by EPA's Office of Research and Development and have been collectively referred to as the "National O & M Cause and Effect Survey" (1,2,3,4).

Conclusions of these research efforts can be broadly summarized in two categories: conclusions on all facilities and conclusions concerning inidividual treatment plants. For all facilities it was determined that individual facilities are hindered from achieving desired performance by multiple factors unique to each facility. As such, specific programs implemented to address selected factors at all facilities will have a limited correlation between program implementation and improved performance at individual plants. This conclusion is significant in that broad scale programs normally are assessed on their most obvious intended impact. It is thus conceivable that programs could be excluded from development or eliminated because of their inability to show a direct correlation between program implementation and improved plant performance. Yet these programs may be very necessary to address the high ranking and frequently occurring performance limiting factors indentified.

For individual plants it was concluded that multiple and unique factors limit a facility's performance. The scope of these factors is often beyond the plant operator's control (i.e., improper technical guidance and design deficiencies). To achieve a direct correlation between an individual plant's performance and program implementation, a comprehensive site specific effort is required. The comprehensive site specific program was described in concept as a Composite Correction Program (CCP). The purpose of such a program is to address the multiple and unique factors that limit a facility's performance.

An evaluation that was completed for the 50 plants studied in the original EPA research is shown in Table 1. At the start of the research project, 13 out of 50 facilities were consistently meeting secondary treatment standards. In other words, 37 facilities were frequently violating secondary treatment standards which was defined as 30 mg/l BOD_5 and TSS. By looking at the factors limiting performance, an assessment was made that 40 of the 50 facilities could consistently meet secondary treatment standards without a major facility upgrade and only ten would require some kind of upgrade. Nine of those ten that would require an upgrade were trickling filter facilities. Most of the evaluations were done at plants in northern climates so there was a direct relation with climate and the affect on projected trickling filter performance. The potential for broad scale improvement without major upgrades represented an appealing aspect of the research results.

TABLE 1. PERFORMANCE OF 50 PLANTS VS. SECONDARY TREATMENT STANDARDS (4)

	Standards Frequently Violated	Standards Consistently Met
Prior to Evaluation	37	13
Potential Without Upgrade	10	40

CASE HISTORIES

Case histories demonstrating the Composite Correction Program (CCP) approach for two facilities will be presented.

CASE HISTORY - PLANT A

A. Description

Plant A is a 1700 cum/day (0.45) mgd contact-stabilization activated sludge plant. Wastewater treatment processes include flow measurement, contact-stabilization activated sludge, secondary clarification, and chlorine disinfection. About 25 percent of the influent wastewater can be diverted to sewage lagoons for land application purposes. Sludge handling includes treatment in aerobic digesters and land application of liquid sludge.

B. Current Process Loading

TABLE 2. SUMMARY OF PROCESS LAODINGS FOR PLANT A

Parameter	Units	Value
Raw Sewage		
Flow	cum/d (mgd)	1070 (0.28)
BOD_5	mg/l	210
TSS	mg/l	209
Contact Stabilization		
Contact Basin Wastewater Dention Time	hrs	2.1
*Reaeration Detention Time	hrs	13
**Organic Loading	gm/day/cum (lb BOD_5/day/1000 cu ft)	336 (21)
Secondary Clarifier		
Surface Loading	cum/day/sq m (gpd/sq ft)	23.7 (580)

*Based on 100% return flow percentage

**Based on contact plus reaeration volume

C. Factors Addressed During CCP

Administration:

1. Modified permit to allow discharge from contact-stabilization plant and not "polishing pond".

2. Emphasized priority for sludge disposal and obtained commitment for sufficient manpower and equipment to accomplish the task.

Operation:

1. Implemented improved and expanded process control and sludge wasting program.

2. Developed operator skills in making process control adjustments based on proper interpretation of test results.

Design:

1. Modified piping to direct raw sewage to ponds and/or to plant.

2. Obtained sludge hauling truck and installed sludge measuring devices.

Maintenance:

1. Repaired leak in walls between aerobic digester, reaeration basin and contact basin.

2. Repaired raw sewage flow meter and chlorine feed system.

D. Performance

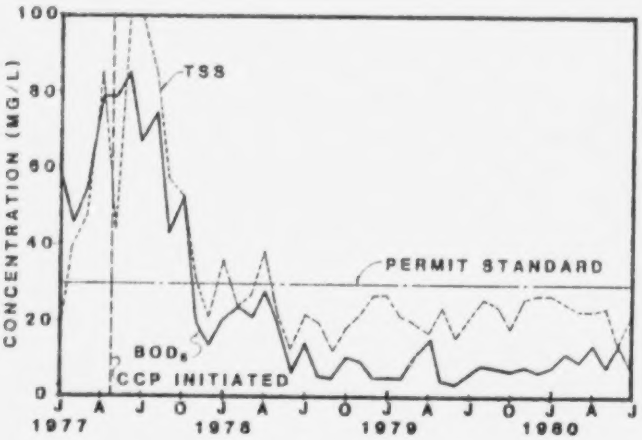


FIGURE 1. Plant A Effluent Quality

E. Discussion

At the start of the CCP Plant A was rated as a 1140 cum/day (300,000 gpd) facility and had received a Cease and Desist Order from the state regulatory agency for frequent violations of its effluent BOD_5 and TSS limitations. When the plant consistently achieved effluent compliance at flows greater than 1140 cum/day (300,000 gpd), its capacity was officially upgraded to 1700 cum/day (450,000 gpd). As such, a threatened tap moratorium by the State was avoided. Over twelve months were required to obtain optimum, stable performance. The impact of improved process control was demonstrated by the ability to avoid wide fluctuations in final effluent quality. Improved performance plus a dramatic increase in plant capacity were the major aspects of this CCP.

CASE HISTORY - PLANT E

A. Description

Plant E is a 5680 cum/day (1.5 mgd) activated sludge facility. Wastewater treatment processes include a flow diversion structure, flow measurement, screening, grit removal, lift station, activated sludge aeration, secondary clarification, disinfection, and a holding pond. Effluent from the ponds is discharged to the river and/or to multi-media filtration and land application for reuse. Sludge is wasted to a regional facility for processing.

B. Current Process Loading

TABLE 3. SUMMARY OF PROCESS LOADINGS FOR PLANT E

Parameter	Units	Value
Raw Sewage		
Flow	cum/day (mgd)	5675 (1.50)
BOD_5	mg/l	195
TSS	mg/l	160
Effluent		
BOD_5	mg/l	8
TSS	mg/l	14
Activated Sludge		
Wastewater Dentention Time	hrs	11
Organic Loading	gm/day/cum (lb BOD_5/day/ 1000 cu ft)	424 (26.5)
Secondary Clarifier		
Surface Loading	cum/day/sq m (gpd/sq ft)	24.4 (597)

C. Factors Addressed During CCP

Administration:

1. Improved communication between laboratory personnel and plant staff.
2. Modified shift coverage to improve process control capability.

Operation:

1. Implemented improved and expanded process control program.
2. Changed the mode of operation from complete mix to plug flow.
3. Adjusted return sludge, waste sludge and dissolved oxygen levels.
4. Developed operator skills in making process control adjustments.

Design:

1. Modified aeration basin discharge overflow weirs.
2. Installed valve to control flow splitting to final clarifiers.
3. Modified flow splitter to aeration basins.
4. Changed the drive on aerators to increase speed.

Maintenance:

1. No changes.

D. Performance

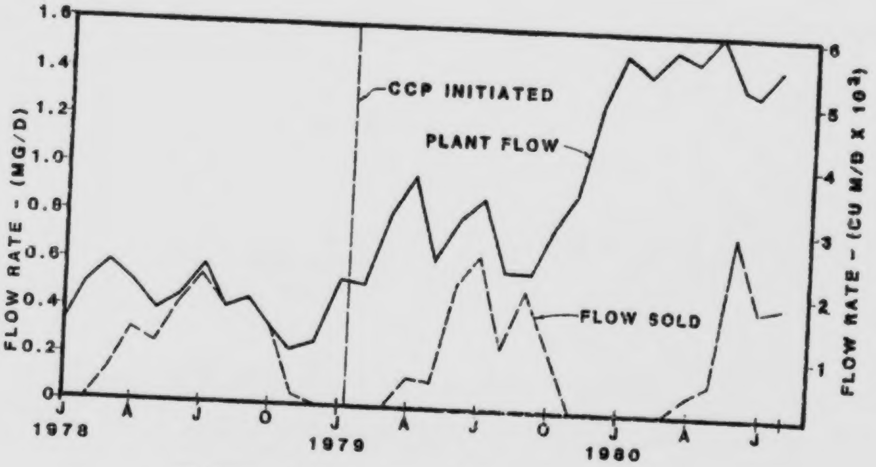


FIGURE 2. Plant E Wastewater Flow

E. Discussion

Plant E was located adjacent to a large interceptor and was capable of treating selected amounts of sewage. Remaining flow was treated by a downstream facility. Increased treatment capacity meant decreased charges from the downstream plant. In addition, increased capacity made more water available for reuse to irrigate a golf course. A severe sludge bulking problem had limited this facility's ability to treat increased flows. Using the CCP approach the plant flow capacity for 1979 was increased 90 percent over 1978 values. Flows for 1980 were increased by 350 percent. Effluent standards have consistently been met throughout these flow increases. A $55,000 annual cost savings for 1980 was projected, due to decreased charges from the downstream facility. An additional benefit was that water availability for reuse was no longer limited by plant capacity. During this CCP the benefits of optimizing process control to obtain maximum capacity from existing facilities was clearly demonstrated.

COLORADO PROJECT

The Environmental Protection Agency (EPA) gave a grant to the State of Colorado to try and demonstrate the effectiveness of the CCP and how it might be utilized to improve facility performance on an areawide basis. The project was enforcement related in that all of the activities in this project were carried out under the Enforcement Division of the Colorado Department of Health, and each plant evaluated was aware of the potential enforcement action. Three steps were involved in the project:

1. The State and EPA jointly identified poor performing facilities.
2. M & I, Inc. was to conduct comprehensive evaluations (3,4) at the identified plants.
3. M & I, Inc. was to implement CCP programs and achieve the desired performance.

Some of the initial results will be summarized. Many of the owners did not realize their responsibility for achieving compliance at a wastewater treatment facility. In initial interviews with the facility owners, which was part of the evaluation effort, many felt that the regulatory agency, the design engineer, the operator, the equipment supplier and others were responsible for the performance of their plant. They were confused in summarizing their particular responsibility in achieving compliance at their facility.

Another result was that much confusion was found to exist among plant owners and personnel if the State or EPA focused on specifics like the need for grounds maintenance or plant fencing during an evaluation. It was observed that recommendations made by a regulatory agency resulted in tremendous effort and enthusiasm to address these suggestions often at the expense of efforts to improve plant performance. Plant owners place a priority on regulatory agency recommendations, often at the expense of focusing efforts on plant performance as a goal. In addition, many owners had implemented specific recommendations from regulatory agencies only to find that desired performance had not been achieved and the regulatory agency had returned. In one case, a facility owner made the comment that if the regulatory agency came back one more time, they would turn the keys for the plant over to them. Another confusing aspect for owners was their understanding of the regulatory role. Do they enforce or do they assist? On numerous occasions regulators had taken an active role in directing specific aspects of a facility's operations. By doing so, they assumed a portion of the responsibility for plant performance in the eyes of the owner. This also has served to confuse the owner as to what his true responsibility is in achieving compliance. The important aspect of these results is that it indicates that the regulatory agency may be better off to let the owner develop their own specific actions while emphasizing owner responsibility to achieve plant performance.

A couple of other results can be placed into the broad categories of political and training limitations.

Political Limitations - We found in a very real sense that the construction grants program is rewarding poor performance. In our original research study we always initiated efforts by holding discussions with the owners and explained the possibility of improving performance. At an unnamed plant in Wyoming one owner said, "We don't want your help. We just got high enough on the priority list to get funding for a new facility, and if we improve performance, we could lose our priority ranking." As such, a negative incentive has resulted to a degree from the grants program.

Another key limitation in our original research and in the State of Colorado study was identifying a poor performing plant. Much discussion has centered on the definitions of poor performance, i.e., how many months does it take to be out of compliance, how may bad samples, and what constitutes a good sampling program to document poor performance. In the Colorado study we attempted to use the NPDES discharge monitoring reports. This approach allowed identification of a few facilities but does not appear adequate as a true indicator of a plant's performance. Presently, the job of identifying a poor performer often falls upon regulatory agency field personnel. Problems that these regulatory people face in assuming this responsibility will be discussed later.

Training Limitations - The third ranking factor limiting wastewater treatment plant performance identified in our original research (4) was improper technical guidance. This factor still exists. For example, almost each month you can pick up a technical publication and find conflicting reports. Particular topics especially subject to conflicting reports are causes and cures for bulking sludge or the impact of side streams on process performance. Often, magnitudes of difference may exist in the descriptions of an approach to take to correct these problems. Other claims that have remained flagrant are those describing activated sludge processes that never require wasting of sludge and that need little or no attention to operate. Another training limitation that also still exists is operator application of concepts. Many operators have had a great deal of classroom training but cannot apply this training to their particular facility. What has worked to overcome this limitation is on-site training specific to a particular facility.

A lack of authoritative understanding of process capability also represents a training limitation. Authoritative understanding and specifics of process capability for biological systems is admittedly a tough area to quantify. However, the continuing disagreement of "experts" has done little to make the field more easily understood. For example, if you put activated sludge "experts" in one room, it would be difficult to conclude what constitutes good settling sludge, what constitutes poor settling sludge, what constitutes good return rates, etc. As such, a lot of confusion exists as to the exact capability that can be expected from the activated sludge process. Process understanding and capability are important to everyone that is involved in evaluating wastewater treatment facilities. It has been documented that many factors limit a facility's performance (3,4). These factors can be administrative, design, operation or maintenance related. They can all appear to have equal weight and importance especially if a facility is out of compliance. How then do you set priorities on what should be addressed first?

The necessary first step is process understanding. With good process understanding you can put priorities on maintenance, design or administration limitations to support the process needs. Without process understanding as a basis, priority setting becomes a maze of trial and error efforts.

Several unresolved issues remain in trying to develop an areawide compliance strategy for the Colorado CCP project. A focus on performance can be achieved through enforcement. Indeed many of the plants that we have been able to go into and improve and directly address performance problems have been because the owner's focus was brought to bear by an enforcement activity. However, there has been some reluctance to use enforcement as a very strong tool to bring this focus about. Should enforcement be stronger to accelerate the understanding of the plant performance/owner responsibility relationship?

A second step is identifying poor performance. A regulatory agency is in a tough role in making an initial assessment. Ideally, they should not make specific recommendations at a particular facility nor should they make interim recommendations. Yet they have to get the facility owner to focus on performance. To accomplish these objectives, the evaluator must have an idea of the steps that are probably logical to get a plant from its present state to compliance without dictating the steps to the owner. Otherwise, he will confuse and cloud the focus on performance. Another unresolved issue is who should conduct comprehensive evaluations or conduct CCP's. Should that be a role of the EPA or state agencies or should it be done privately? The tools are available to improve performance. The mechanisms to provide impetus to using these tools are apparently lacking.

REFERENCES

1. Gannett, Fleming, Cordry and Carpenter, Consulting Engineers, Harrisburg, Pennsylvania. Evaluation of Operation and Maintenance Factors Limiting Biological Wastewater Treatment Plant Performance. Report No. EPA-600/2-79-087 (July 1979).

2. Hegg, B. A., K. L. Rakness and J. R. Schultz. A Demonstrated Approach for Improving Performance and Reliability of Biological Wastewater Treatment Plants. M & I, Inc., Consulting Engineers, Fort Collins, Colorado, Report No. EPA-6-00/2-79-035 (June 1979).

3. Hegg, B. A., K. L. Rakness and J. R. Schultz. Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance. M & I, Inc., Consulting Engineers, Fort Collins, Colorado, Report No. EPA-600/2-79-034 (June 1979).

4. Hegg, B. A., K. L. Rakness and J. R. Schultz. Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance - Phase II, M & I, Inc., Consulting Engineers, Fort Collins, Colorado, Report No. EPA-600/2-80-129 (August 1980).

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

PAPER NO. 7

APPLICATION OF INTRACHANNEL CLARIFIERS
IN THE OXIDATION DITCH PROCESS

by

Harold J. Beard
President

Beard Engineering, Inc.
P.O. Box 3838
Baton Rouge, Louisiana 70821 3838

APPLICATION OF INTRACHANNEL CLARIFIERS IN THE OXIDATION DITCH PROCESS

Harold J. Beard, President
Beard Engineering, Inc.

INTRODUCTION

Conventional solutions to the wastewater enigma faced by many communities today, often results in high capital expenditure, as well as increasing operation and maintenance costs over the life of the project. The increasing awareness of the need for energy conservation has led many EPA construction grant applicants to the EPA Innovative/Alternative Program which Congress incorporated into the Clean Water Act of 1977. The purpose of the I/A program is to develop new technologies that will meet required effluent limits with a minimum amount of resources. Since its introduction, communities have had the incentive to utilize this program because of the associated cost savings. That is, the federal government would pay for 85% of design and construction of all or part of a treatment process determined to meet the requirements of the I/A program. Even though communities and their consultants have been required to look at alternatives for treatment since the enactment of the Federal Water Pollution Control Act Amendment of 1972, it was not until the introduction of promised cost and energy savings that the program was vigorously embraced. As a result, consulting engineers have gone beyond the alternative technologies of land treatment and sludge composting to advance the state-of-the-art by the introduction of innovative technology to conventional treatment schemes.

One of the most common conventional treatment schemes utilized to meet effluent standards imposed as a result of individual discharge stream requirements is that of activated sludge treatment for biological oxidation of organic material present in influent wastewater. The purpose of this paper is to describe the innovative technologies applied to the activated sludge treatment process found to be most suitable for the city of Winnfield, Louisiana.

The existing Winnfield, La. wastewater treatment facility consisted of a 1.2 - mgd single stage high rate trickling filter system with an anaerobic single stage sludge digester and drying beds. The alternatives evaluated were subject to a detailed analysis to determine the one that would be most cost-effective, implementable, environmentally sound and energy efficient, and yet would be simple to operate and maintain. A multi-screening process eliminated those treatment schemes that would not satisfy a majority of the present guidelines such as unavailability of land, resource conservation and use of existing structures. The alternative system that adequately satisfied the selection criteria and was subsequently selected through a detailed analysis of effluent requirements, wastewater characteristics, capital cost, operating cost, energy consumption and sludge handling and environmental consideration was an extended aeration process utilizing an oxidation ditch with intrachannel clarifiers.

IMMEDIATE ADVANTAGES OF THE INTRACHANNEL CLARIFIER

Design criteria for an oxidation ditch is based on the theoretical destruction of all organic matter applied by using an extended aeration period and increased aeration. The raw wastewater flow is fed directly to the ditch where the contents are aerated and kept in continual motion. The aerated sewage is then passed to a final settling tank which utilizes mechanical scraping devices to move settled active solids to a collection point in the tank. A portion of the collected sludge is then picked up by return sludge pumping system and returned to the oxidation ditch in order to maintain a desired mixed liquor suspended solids concentration. (1)

A most obvious advantage to the "intrachannel clarifier" system of mixed liquor clarification is the significant savings associated with both energy consumption and construction. In contrast with the conventional external clarifier which requires feed and/or return sludge pumping, once the influent has been fed to the oxidation ditch, except for aeration purposes, no further energy consumption is required for clarification purposes. Since no external basin is required, there is also a definite savings in construction costs. Any treatment system selected should be relatively simple and easily operable by an operator of medium skill and training. The process equipment and controls should not be highly sophisticated. An additional advantage to be realized of the "intrachannel clarifier" is the possible reduction in plant operational expertise required with respect to sludge waste and return pumping associated with maintaining optimum MLSS concentration.

In June of 1981, a proposal was submitted by the city of Winnfield, Louisiana to the EPA Municipal Environmental Research Laboratory for the purpose of requesting a Research Cooperative Agreement for bench and pilot scale testing of an intrachannel clarifier design. Evaluation of various clarifier designs would be in conjunction with an anticipated EPA Step 2 Construction Grant for proposed wastewater treatment facilities.

Previous testing of an intrachannel final clarifier in the oxidation ditch at the wastewater treatment facility located in Campbellsville, Kentucky led to the first generation development of a unique final sedimentation process. This intrachannel clarifier system was shown to provide significant construction and energy cost savings as compared to conventional final clarifiers. However, the results of this testing has led the staff of Beard Engineering, Inc. to the identification of several variables which when optimized, may significantly enhance the clarifier performance, and result in additional cost savings. Since the intrachannel clarifier was shown to provide satisfactory clarification and sludge return characteristics for a secondary treatment level, consideration has been given to the possibility of improving the concept by eliminating the need for sludge scraping mechanisms. The first generation intrachannel system utilized scraper mechanisms for both sludge and scum removal.

It is the intent of the research program to utilize developed mathematical models and calculations to successfully design and subsequently construct an intrachannel clarifier which can substantially reduce the capital and O&M costs required for sewage treatment.

INTRACHANNEL CLARIFIER CONCEPT

The boat shaped clarifier operates within the channel of an oxidation ditch, thereby immediately returning sludge to the mixed liquor stream. With placement of the unit in the direct flow of the mixed liquor, the stream flow is restricted to that channel area between the clarifier and the bottom of the ditch and between the walls of the ditch and the unit. In the area of the channel beneath the "boat clarifier" the velocity of the stream is therefore increased and a net head difference is produced. Because the bottom of the unit is open at various locations with variable sludge ports, this head differential is sufficient to actually pull a quantity of flow and therefore the settled sludge from the inside of the clarifier and back into the mixed liquor stream. It is for this reason that no sludge pumping or scraping is required.

The head differential created by the restriction of the stream flow will also result in a lowering of the channel depth along the sides of the boat clarifier.(2,3) This difference of water levels between the inside and the outside of the clarifier will allow for the removal of floating debris in the clarifier. Surface baffles within the boat will direct floatables towards several adjustable scum ports on both sides of the unit. The debris will be returned to the ditch through these scum ports and will be continuously removed from the ditch surface with additional baffling.

RESTRICTION OF FLOW

As previously mentioned, the boat clarifier concept operates on the principal that as flow is restricted in a channel, this transition produces a net head difference less than that of the flow prior to this transition. So that a minimum of loss occurs in the available head difference produced, the cross sectional surface area of the boat and its front end design are critical to tranquil flow around and beneath the clarifier. A mathematical analysis of eleven (11) different cross sectional shapes was performed to determine which would achieve the maximum velocity increase beneath the clarifier in a rectangular channel and yet expose the smallest amount of surface area to the stream flow in order to minimize frictional losses of energy. In a rectangular open channel, we know that flow is equal to the velocity times the cross sectional area of the channel. With the flow remaining constant in the channel and through the restricted area beneath the boat, the velocity in the restricted area would then be a function of the cross sectional areas as follows:

$$V_2 = \frac{V_1 A_1}{A_2}$$

Where A_1, and V_1 are associated with the channel upstream of the clarifier and A_2, and V_2 are associated with the mixed liquor stream beneath and around the clarifier.

CHANNEL WATER LEVEL AND CRITICAL DEPTH

Having determined the ideal clarifier cross section for a rectangular channel, the proper operating depth of the clarifier can be established considering the water level and velocity in the channel. Clarifier depth in the channel must produce a sufficiently large head differential to provide proper skimming and sludge return flows. Therefore, there is a minimum clarifier depth required for proper operation.

The maximum clarifier depth is that depth at which a hydraulic jump will occur. If this "critical depth" is exceeded, high velocity in the restricted area beneath the clarifier will result in a hydraulic jump where the channel flow exits the restricted area. A hydraulic jump must be avoided since its turbulence results in a large loss of energy. (Figure 1) (4)

Therefore, for a given velocity and water level in the channel there is a certain minimum and maximum clarifier depth. Calculations were performed using five different water levels, three clarifier depths, the selected channel cross section, and a channel velocity of 1 ft/sec. Similar calculations were performed using a velocity of 1.5 ft/sec to evaluate the clarifier depths required for the normal velocity range of oxidation ditches.

These calculations were used to plot curves of velocity beneath the clarifier vs. water level in the channel at the three clarifier depths and two channel velocities. A critical depth curve was plotted using the velocity at critical depth for each water level and each channel velocity. The resulting plot (Figure 2) can be used to find the maximum clarifier depth for a given water level at a velocity in the channel of 1 fps. Similar curves can be developed for other stream velocities in the channel.

The calculations were also used to plot curves of head differential vs. water level in the channel at the three clarifier depths and two channel velocities. Therefore, for a certain clarifier depth, channel water level, and channel velocity the curves can be used to find the head differential. If head differential is known then the skimming and sludge return flows can be calculated. (Figure 3)

In summary, this clarifier design involves developing a set of curves of velocity beneath the clarifier vs. channel water level. These curves are used to determine the maximum allowable clarifier depth for a certain water level and velocity in the channel. A second set of curves of head differential vs. channel water level can be used to calculate skimming and sludge return flows for a certain clarifier depth, channel water level, and channel velocity.

SLUDGE CHARACTERISTICS

An evaluation of sludge settling characteristics must be included in order to properly design the clarifier internals. For evaluation purposes an artificial sludge was produced utilizing ferric chloride. This sludge was prepared to have a Sludge Volume Index of 73 at a solids concentration of 3000 mg/l. Thus, the settling characteristics of this iron sludge were very similar to typical activated sludge in a domestic wastewater treatment plant.

Settling column tests were performed by recording the interface height at regular time intervals as the sludge blanket settled in a one liter graduated cylinder. This data was then used to develop the settling curve shown in Figure 4. Analysis of this curve reveals that a compressive settling zone is formed in approximately nine minutes when the sludge blanket occupies 46% of the volume of the cylinder.

As shown in the lower portion of this curve, settling of the sludge blanket is considerably slower once the compressive zone is formed. This type of settling occurs in the bottom portion of a conventional clarifier where the sludge is collected and pumped from the clarifier basin. Since settling sludge is rapidly returned to the mixed liquor stream via ports distributed over the entire floor of the boat clarifier, there will be no formation of a compressive zone. For this reason the boat clarifier operates more as a phase separator continuously drawing off sludge, rather than a conventional and somewhat quiescent settling basin which requires bottom scraping.

To dramatize the effects of continuous sludge draw off, a more realistic settling test was developed utilizing a graduated cylinder from which the artificial sludge was withdrawn from the bottom at various rates of millimeters/minute.

This test data was used to develop the settling curves shown in Figure 5. These curves are a graphical presentation of a column of influent water as it moves through the length of the boat towards the bow. It is anticipated that these curves will represent the actual shape of the sludge blanket which will form subsequent to various adjustments of the sludge ports.

From the previous settling column tests, it was determined that ultimate settling would result in a sludge blanket which would occupy 13% of the volume of the cylinder. To represent the effects of sludge draw off on the volume of sludge per unit volume of the clarifier, the initial settling curve in Figure 4 was converted to the percentage curve shown in Figure 6. Analysis of this curve reveals that as the total volume of the cylinder decreases, a direct result of draw off, the percentage of sludge in the remaining volume increases. For example, in 18 minutes the sludge occupies 45% of the remaining volume and at 28 minutes it occupies 56% of the volume.

In combining the results of the settling tests, it was concluded that the sludge blanket which will form in the boat clarifier will be affected by the percentage of boat volume removed through the sludge ports and the amount of time required for the flow to move the length of the clarifier.

ANALYSIS OF CLARIFIER FLOWS

In order to determine the optimum amount of clarifier volume which should be removed through the sludge ports, it was necessary to perform an analysis of all flows in the clarifier.

Initially it must be recognized that the flow into the rear of the clarifier is determined entirely by what is removed from the effluent launderers (Q_1), the surface skimmer (Q_2), and the sludge return ports (Q_3) on the bottom.

The value of Q_1 is determined by plant capacity and is therefore a constant. The value of Q_2 is such that movement of the surface water is sufficient to remove floating debris through the skimming ports. For the purpose of developing a mathematical model, it is assumed that $Q_1 = Q_2$ and therefore Q_3 can be varied to determine its effect on the sludge blanket formation. In the analysis it was assumed that the bottom of the clarifier was evenly spaced with the (10) sludge ports. With the ultimate sludge settling volume of 13% in mind, the percentage of sludge per unit volume of the clarifier was determined for 10 cummulative time intervals. These determinations were made for various Q_3 values and resulting total volumes $(Q_T) = Q_1 + Q_2 + Q_3$. The resulting percentages were then used to determine approximately how much flow (Q_3) was being removed in excess to that which would be required to remove the average volume of sludge. These excess amounts, or "safety factors" were then plotted against their respective Q_3 to Q_T ratios.

To dramatize the effect of flow time in the clarifier, a similar curve was developed with effluent launders placed in the rear of the boat where the influent comes in.

Mathematical models were also done on uneven flows on the ten port openings with the greatest flow being from the rear of the boat clarifier where the initial wastewater flows into the clarifier and the smallest flow from the bow where the launders were located. These results showed an improvement in removal over the equal flows. In these calculations the same ratios of Q_3 to Q_T were utilized as with the ten even flows so that relative data and effects could be established.

The resulting Figure 7 reveals that the maximum efficiency of sludge removal occurs when approximately 64% to 65% of Q_T is removed through the sludge ports and the effluent launders are located in the bow of the boat.

SLUDGE FLOW FROM CLARIFIER BOTTOM

The two determining factors which effect the flow from the sludge ports on the bottom of the clarifier are the head differential produced by the restriction of flow and the size of the ports themselves.

For the purpose of this explanation, the following assumptions were made:

A) The velocity in the channel is 1 ft/sec.

B) The cross sectional area of the channel is 11.52 ft^2/linear foot.

C) The skimmer port is set at .5" below the water level when the channel is not flowing.

D) The head loss under the clarifier is 1 inch.

Assuming the bottom of the clarifier is .750 ft. from the bottom of the channel and the water level is at 2.4 ft., the total head differential is then 1.91 inches (head differential created by difference in velocity based on Bernoulli).

Therefore, the available head for sludge flow Q_3 is:

$$1.91'' - 1.0'' - .5'' = .41''$$

The velocity exiting the bottom (less opening losses is determined by the equation $V = \sqrt{2gh}$. Therefore, the exit velocity is:

$$V_3 = \sqrt{2 \times 32.2 \times \frac{.41}{12}}$$

$$V_3 = 1.48 \text{ ft./sec.}$$

This velocity then allows the calculation of the total opened area in the bottom required to achieve a Q_3 of 64% to 65% of Q_T.

Recognizing that there are numerous variables that effect the amount of open area, it is advisable to have the bottom of the clarifier designed so that the sludge port opening can be varied.

The proposed bench scale model will be built identical to the full scale system with all influent ports, effluent weirs, and scum and sludge removal ports being operational and variable.

Initial testing will involve determination of the most efficient clarifier orientation with respect to the channel bottom and water depth. In our mathematical development of the boat clarifier, headloss beneath the unit was determined for a wood structure. However, since the bench scale model is to be fabricated from fiberglass, it is believed that the actual velocities and head differentials produced by restriction of the channel flow will approach and perhaps surpass those calculated in the mathematical analysis. Velocities and head differentials will be recorded for what is hydraulicaly the most efficient boat configuration utilizing various clarifier and channel depths. The approach channel velocity will also be varied to collect similar data for the normal velocity range common to oxidation ditch wastewater treatment systems.

The next portion of the testing procedure will involve the use of dye or fine bubbles to video record the actual flows produced beneath, around and within the clarifier. This data will allow for actual refinement of the clarifier shape both internally and externally. Again, this will include a variance in the channel and clarifier depths as well as approach velocities.

Finally, once the most efficient boat configuration and orientation have been determined, the same artificial sludge used in the mathematical development will be introduced into the oxidation ditch. Also, sludge and skimmer ports will be adjusted so that optimum flows are achieved for both sludge blanket and floatable solids removal from the clarifier.

At this time it is most important to note the conservative assumptions made during development of this concept. The calculations for determining the optimum Q_3 to Q_T ratio and subsequently the length of the boat clarifier, were based on the assumption that there is a specific amount of time required for the sludge to attain the ultimate compressibility of 13% of total volume. However, since this concept involves continuous removal of sludge it is anticipated that actual testing will result in a much shorter sludge blanket. Also, settling curves where developed for sludge which occupied the entire depth of the settling columns. When the artificial sludge enters the rear of the clarifier, a baffle will direct the flow down towards the sludge removal ports. Therefore, the solids particles will actually start their descent to the bottom of the clarifier at or below the mid-depth point. Again it is anticipated that this will result in a shorter sludge blanket and subsequently quicker removal of all solids.

Upon conclusion of the testing procedure, all pertinent data will be utilized to modify the original mathematical model. It is this resulting configuration and channel requirements upon which design of a pilot model will be based.

REFERENCES

1. John W. Clark et al., Water Supply and Pollution Control, International Textbook Co., New York, 1971.
2. Victor L. Streeter and E. Benjamin Wylie, Fluid Mechanics, 6th ed., McGraw-Hill Book Co., New York, 1975.
3. Calvin Victor Davis and Kenneth E. Sorensen, Handbook of Applied Hydraulics, 3rd ed., McGraw-Hill Book Co., New York, 1970.
4. Metcalf & Eddy, Inc., Wastewater Engineering, McGraw-Hill Book Co., New York, 1972.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

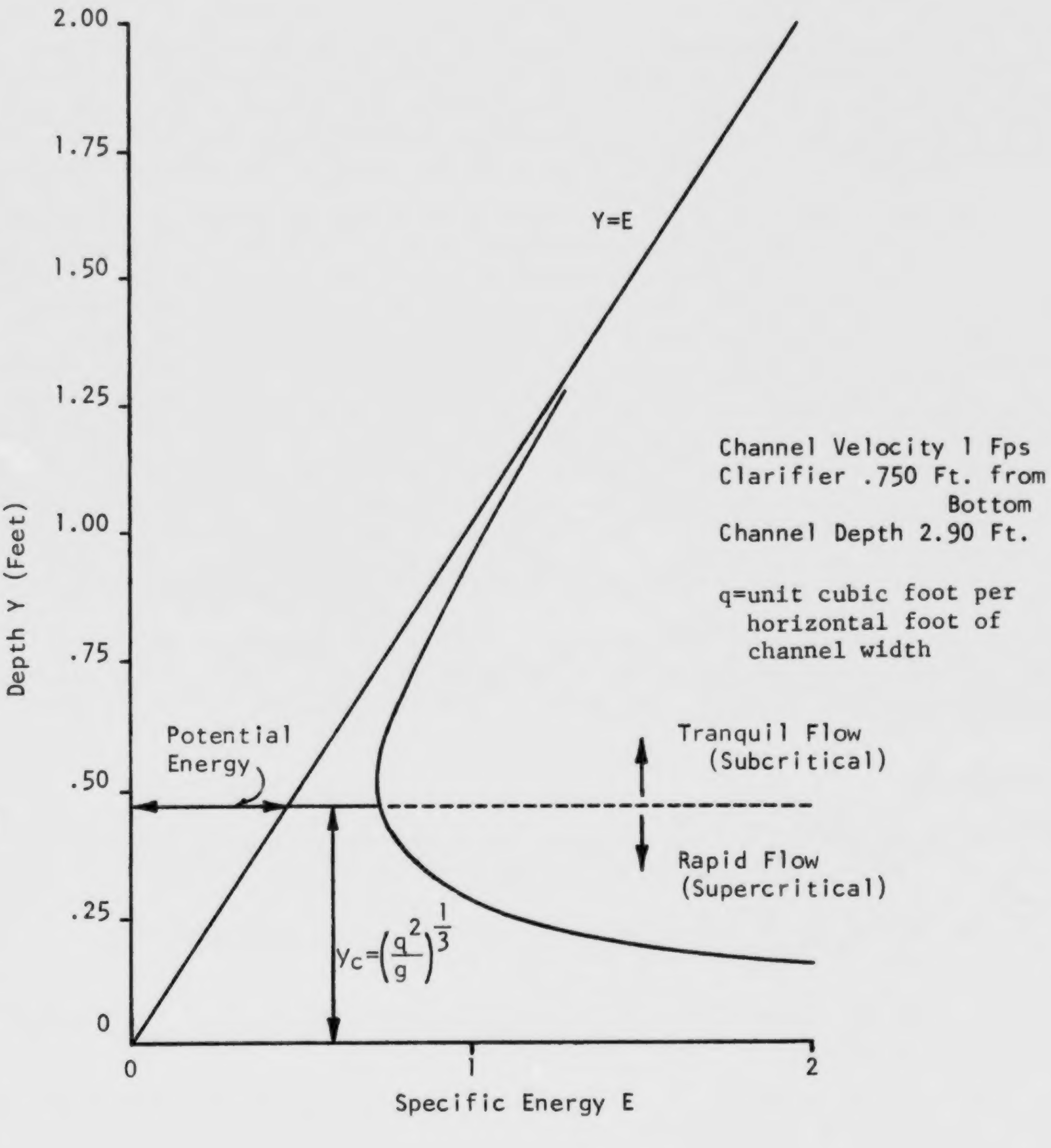


Figure 1. Specific Energy Diagram

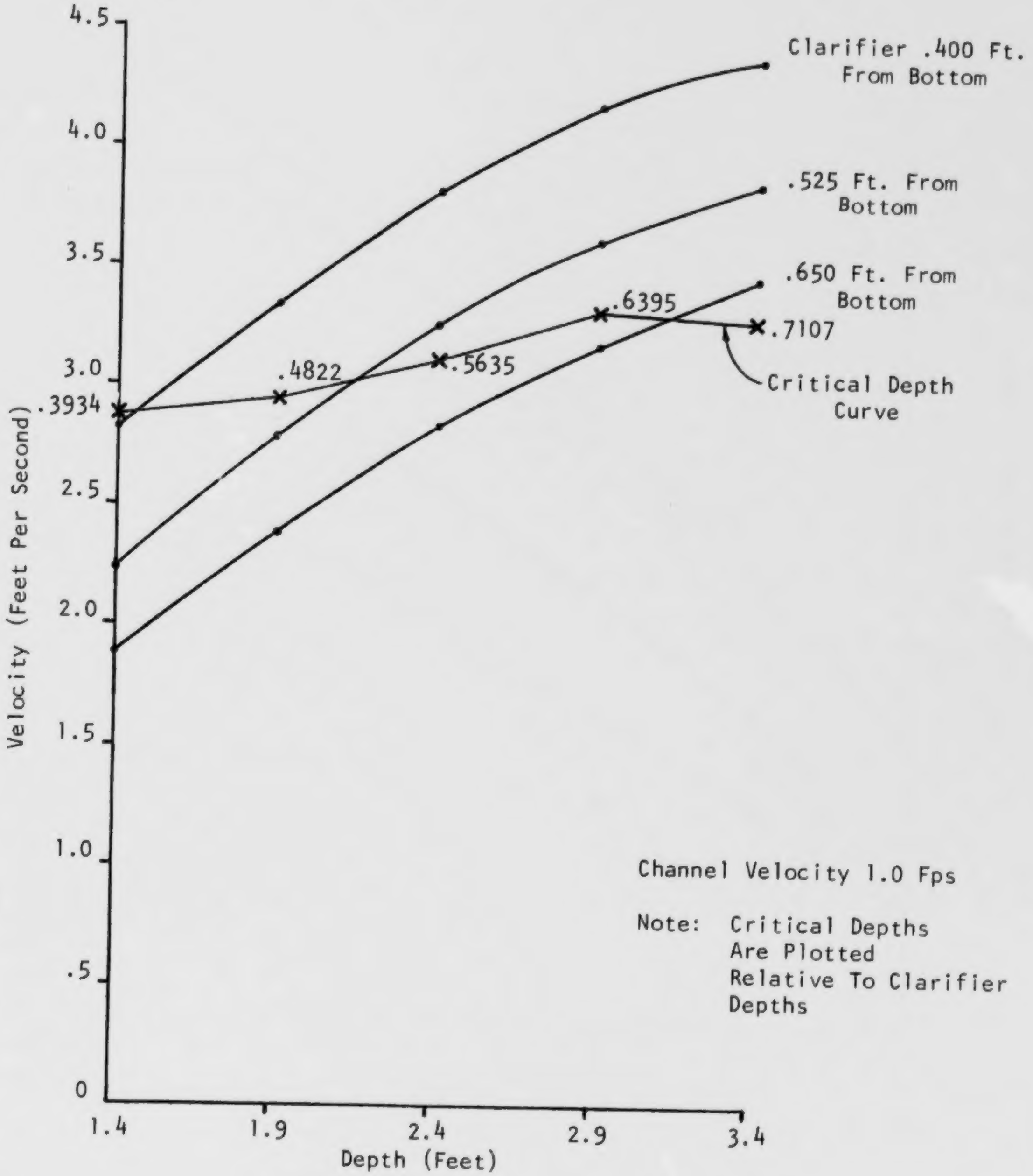


Figure 2. Velocity Beneath Clarifier vs. Channel Depth

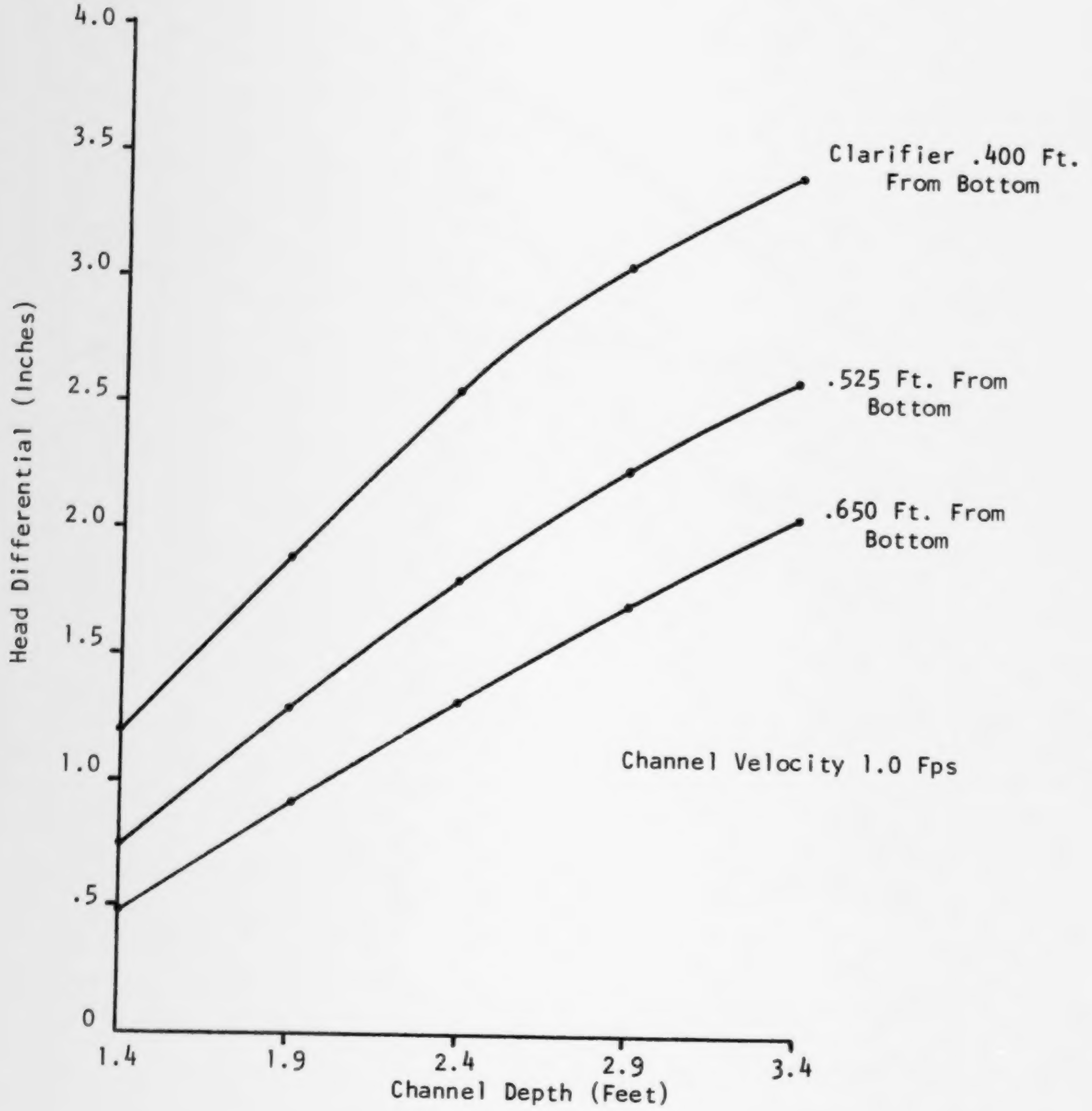


Figure 3. Head Differential vs. Channel Depth

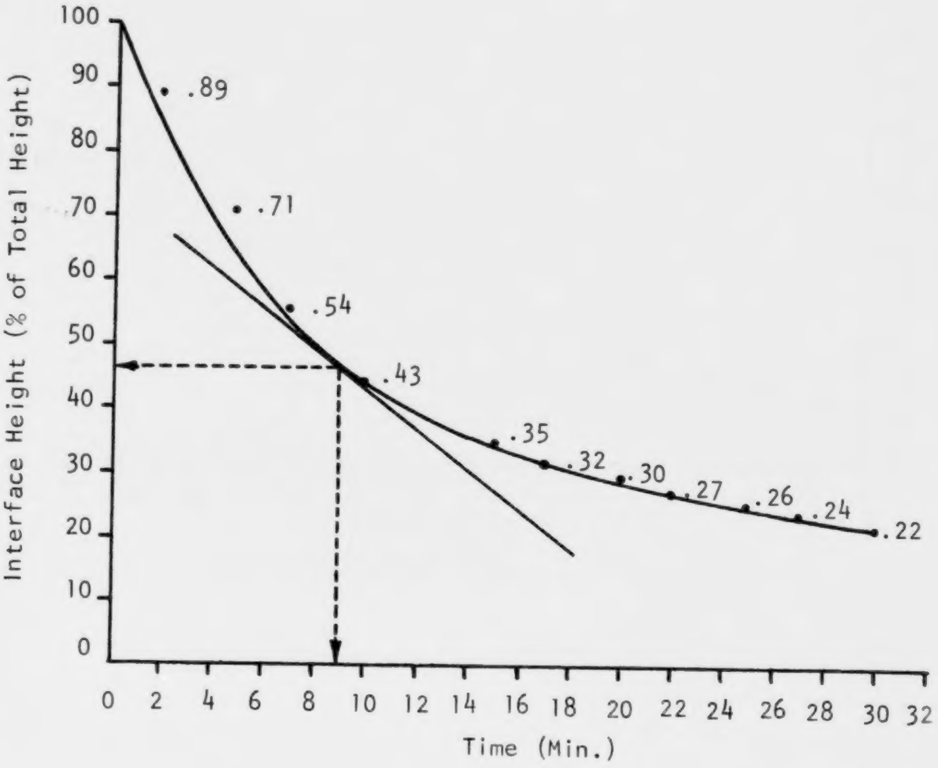


Figure 4. Settling Curve For Artificial Sludge

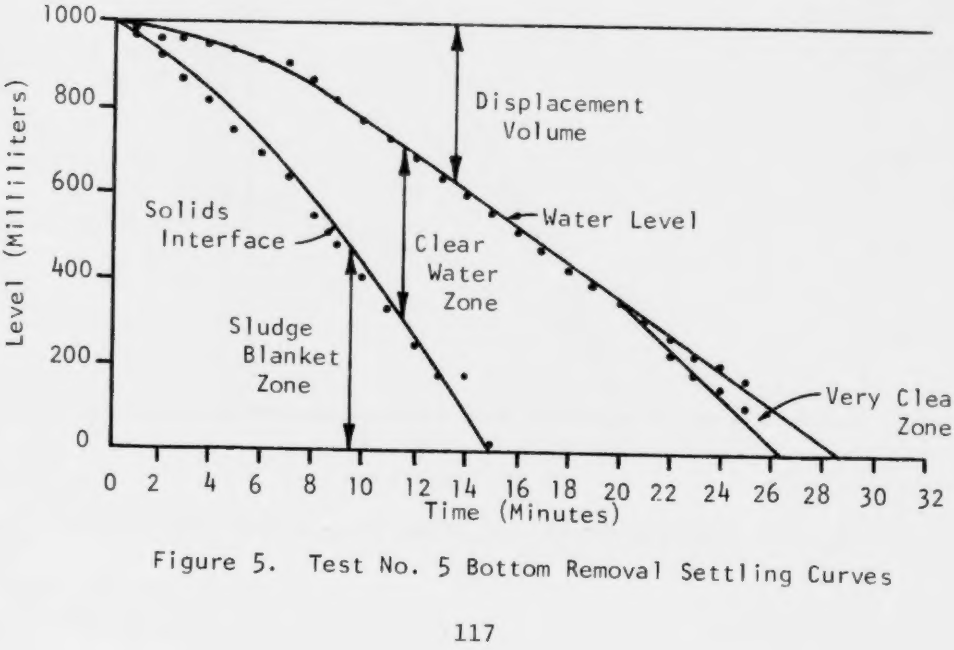


Figure 5. Test No. 5 Bottom Removal Settling Curves

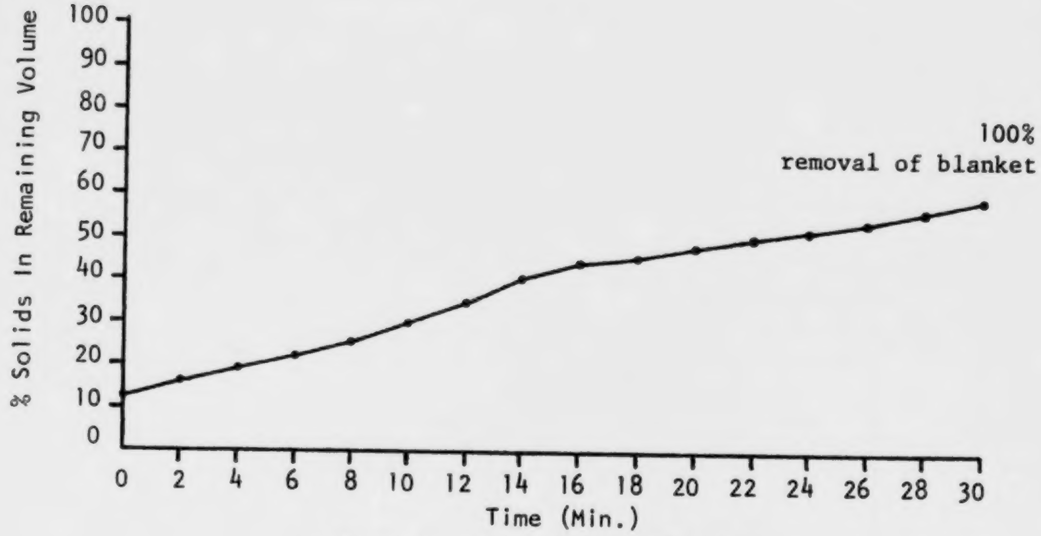


Figure 6. % Of Maximum Settlement

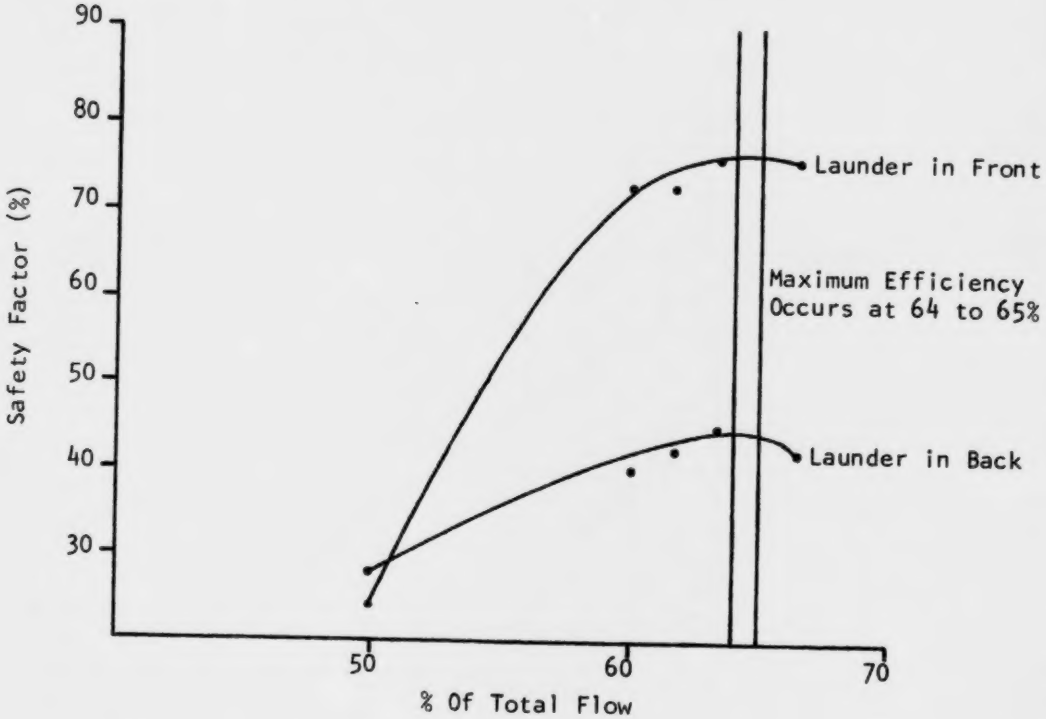


Figure 7. Safety Factor vs. Flow From Bottom Clarifier

PAPER NO. 8

BIOLOGICAL FOULING OF FINE BUBBLE DIFFUSERS

by

William C. Boyle
Professor of Civil & Environmental Engineering
University of Wisconsin
Madison, Wisconsin

and

David T. Redmon
Engineer
Ewing Engineering Company
Milwaukee, Wisconsin

BIOLOGICAL FOULING OF FINE BUBBLE DIFFUSERS

William C. Boyle, Professor of Civil & Environmental Engineering, University of Wisconsin, Madison, WI
David T. Redmon, Engineer, Ewing Engineering Co., Milwaukee, WI

Aerobic biological processes continue to be the most popular methods for the treatment of municipal and industrial wastewaters. The supply of oxygen to the biomass in activated sludge and aerated lagoons represents the single largest energy consumer in the treatment plant. Recent studies indicate that from 50 to 90 percent of the net power demand for a treatment plant lies within the aeration system (1). It is not surprising, therefore, that engineers continue to seek the most efficient aeration systems for new and existing wastewater treatment facilities in order to provide energy-conserving operation.

Although there is considerable controversy over which aeration system provides the most favorable oxygen transfer efficiency, the fine bubble diffusion of air has recently gained renewed popularity as a very competitive high efficiency system. Yet, considerable concern has been registered regarding the maintenance of fine bubble systems owing to their susceptibility to clogging. Diffuser clogging, if severe, may lead to deterioration of aeration efficiency resulting in an escalation of power costs. Furthermore, troublesome maintenance of diffusers may consume a substantial amount of operator time.

Originally, oxygen was diffused into wastewater through perforated pipes located at the bottom of the aeration tank. The development of the porous plate for aeration was considered an important advance in the diffused air process because of the high transfer efficiency of this fine pore diffuser (2). Porous diffuser plates were used in activated sludge processes as early as 1916 and they became the most popular method of aeration by the 1930's (3, 4). Shortly after their installation, however, it became clear that clogging could be a problem. Early work by Bushee and Zack (5) at the Sanitary District of Chicago from 1922 to 1924 prompted the use of coarser media to avoid severe clogging problems. Similar studies confirmed this at Milwaukee in the early 1930's. In a comprehensive review of fine bubble diffuser servicing, Roe (2) outlined a number of causes of diffuser clogging. This list has been expanded over the years and is presented in Table I.

It was clear even in the early years of fine bubble diffusion that clogging was highly site specific and quite often difficult to forecast (4, 6). Diffuser clogging was chronic at some plants after only a few months of operation, yet, at others, virtually no difficulties with clogging arose. Substantial effort was applied in the early years to reducing internal clogging by means of efficient air cleaning (7,8,9), a practice still performed today. External clogging was not as easy to analyze or control, however, and operations research concentrated primarily on treating the symptom rather than the cause.

TABLE I. CAUSES OF DIFFUSER CLOGGING

Air Side

- Dust and dirt from unfiltered air
- Oil from compressors or viscous air filters
- Rust and scale from air pipe corrosion
- Construction debris due to poor clean up
- Wastewater solids entering through diffuser or pipe leaks

Liquor Side

- Fibrous material attached to sharp edges
- Inorganic fines entering media at low or zero air pressure
- Organic solids entering media at low or zero air pressure
- Oils or greases in wastewater
- Precipitated deposits, including iron and carbonates
- Biological growths on diffuser media

TESTS FOR CLOGGING

In 1934, Roe (2) indicated that clogging of air diffusers could best be monitored by measuring air main pressure changes with time for each aeration tank. Further, he indicated that visual observation of the aeration tank surface could often provide evidence of severe diffuser fouling. Over the years, little change has been made in this technique. As indicated by Roe, sequential readings of air main pressure, air flow and temperature are made (Figure 1). A plot of air pressure at a given standard air flow rate versus time is subsequently used to detect fouling. One of the major factors that severely limits the precision of this method is that the differential pressure across the diffusion element itself, which is the parameter of principal interest, is very small relative to the pressure in the main. Other factors and variables that further limit the precision of the method include the water surface elevation in the aeration tanks, water temperature, air flow variation, and variable line losses.

A method that measures the drop across selected diffusion elements at measured flow rates is considered to be of far greater accuracy and precision. An example of such a system is shown in the detail sketch on Fig. 1. Flow may be determined by observation of manometer A which measures the differential across the previously calibrated control orifice C. Manometer B measures the pressure drop across the diffusion element itself, or the dynamic wet pressure (DWP).

Dynamic Wet Pressure

The dynamic wet pressure, DWP, is the pressure differential across the diffusion element alone when operating in a submerged condition and is expressed in terms of inches of water, at some specified flow rate. It differs substantially from the permeability test, where the specific air flow rates are typically much higher and where surface tension of the submerging liquid is not a factor.

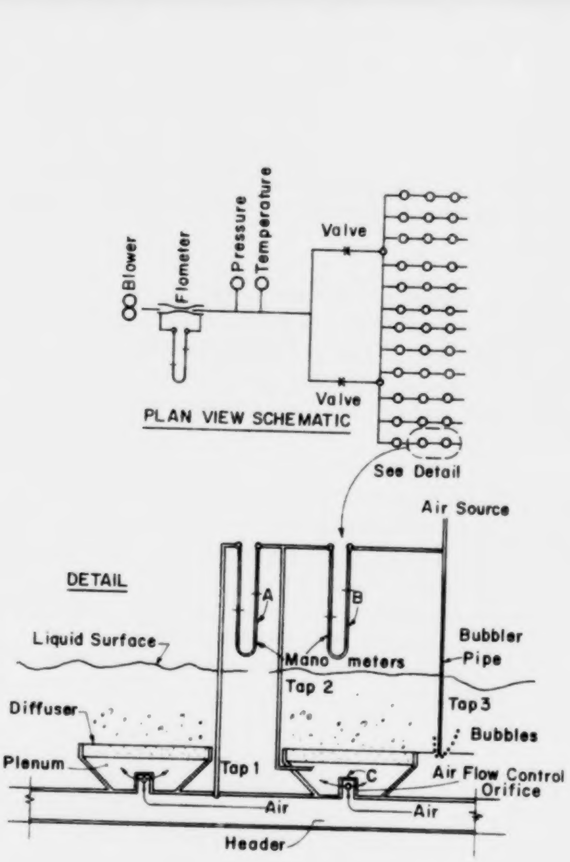

Blower
Flometer
Pressure
Temperature
Valve
Valve
PLAN VIEW SCHEMATIC
See Detail
Air Source
DETAIL
A
B
Liquid Surface
Mano meters
Bubbler Pipe
Tap 2
Tap 3
Diffuser
Bubbles
Plenum
Tap 1
C
Air Flow Control Orifice
Air
Air
Header

Figure 1. Measurement of Air Line and Diffuser Pressure

In the dynamic wet pressure test, most of the pressure differential is due to the force or pressure required to form bubbles against the force of surface tension and only a small fraction of the total pressure gradient is required to overcome frictional resistance.

The DWP is normally relatively insensitive to airflow rate. This results since the surface tension effect is not greatly influenced by flow rate in flow ranges normally applied and the contribution of frictional resistance is a small part of the total pressure gradient.

That the frictional resistance is small with respect to the total, can be shown as follows:

> Assume the typical airflow rate at average design conditions is about 2 SCFM per square foot of diffuser surface area. Since the frictional resistance is only 2.0 in. wg. at 25 SCFM (specific

permeability of 25) and this unit is typically operated at 2 SCFM under average design conditions, its theoretical frictional resistance at this rate is roughly 2.0/25.0 of 2 in. wg. or about 0.2 in. wg. The total DWP at 2.0 SCFM is about 6.9 in. wg. So the frictional resistance at this airflow rate is roughly 3% of the total resistance.

The DWP test is of value in analyzing diffuser fouling in at least two ways. It is a much more sensitive indicator of fouling than air main pressure readings and the analysis of the DWP vs. flow relationship gives some indication of the nature and type of fouling.

Bubble Release Pressure

The bubble release pressure (BRP) test provides a means of comparing the relative effective pore diameter at any point on the surface of a ceramic element to other point(s) on its surface. Ewing Engineering Company developed this test procedure as a tool to assess the uniformity of pores on the surfaces of ceramic diffusers.

The bubble release pressure test, as indicated by the name, measures the pressure in inches of water gauge required to emit bubbles from a localized point on the surface of a submerged and thoroughly wetted porous diffuser element. This is accomplished by forcing air at a very low rate of flow into the diffuser and measuring the pressure of the air when bubbles are released from the diffuser at the point in question.

The test procedure was developed from a similar test found in ASTM, Part 41, under Standard Test Method E128-61. This standard describes a technique for measuring the maximum pore on a porous structure and uses the force to make bubbles in a known fluid to calculate a capillary diameter corresponding to this force or pressure.

Ewing Engineering Company modified the hardware to suit their needs and used BRP observations of a statistically significant number of points on the element to ascertain the degree of uniformity. After determining the air flow distribution on several elements on which BRP data was available, it became apparent that the BRP test data was a sensitive indicator of flow distribution.

This test has been applied to a variety of fine pore diffuser elements. It has been found to be a sensitive indicator of the degree of fouling of porous diffusers and provides a quantitative means of assessing the rate and location of plugging.

Furthermore, analysis of partially fouled diffusers have given indication that the BRP test is even more sensitive than the DWP test. Consequently, in diffuser fouling investigations, the use of these test methods permits significant shortening of the test period required to obtain definitive conclusions about diffuser clogging.

Air Profile Test

The airflow profile test uses quantitative techniques to evaluate the uniformity of air release across the surface of ceramic diffusers while operating rather than appraising uniformity by visual means. This is accomplished by testing the element at an air rate which is approximately equal to 2 SCFM/sq. ft., or at the recommended design rate, with anywhere from 2-8 inches of water over it.

The rate of air release from small areas is measured by displacing water from an inverted graduated cylinder and recording the rate of displacement of water with a stopwatch. The same sites monitored in the BRP test are tested in this procedure. By combining the cylinder area and the rate of air discharge, a flux rate, expressed as SCFM/sq. ft. or other convenient units, can be calculated. By comparing the individual readings with one another, a quantitative measure or graphical representation of the profile can be generated.

The combination of DWP, BRP, and flow profile tests applied to new diffusers and at various stages in their operating history, provides a very useful diagnostic tool in evaluating the rate, the nature and the effect of fouling, be it organic or inorganic, on fine bubble porous diffusion elements. It is also effective in appraising the effectiveness of various cleaning procedures.

BIOFOULING OF DIFFUSERS

The occurrence of biological growths or slimes on fine pore diffusers was recognized early after their application in activated sludge. Roe (2) indicated that biological growths were found on the liquor side of most diffusers in operation. He attributed this growth primarily to the nonuniformity of the diffuser medium. There were very few published reports of serious diffuser clogging problems attributed to biological growths, however. Anderson (9) indicated that fungal growths were commonly found on diffusers at the Sanitary District of Chicago Southwest Plant with heaviest growths occurring in the summer near the influent end of the aeration tanks. These growths produced little measurable effect on air line pressure loss except during the summer of 1944 when an exceptionally heavy growth of *Saprolegnia sp* developed. No reason for the unusual growth that year was cited. Beck (3) reported a severe clogging of diffuser plates after 69 days at the Chicago North Side Works where return sludge was aerated. The plate surfaces, clogged with approximately 1/8 inch of biological slime, were refurbished by aeration over a 45 day period without addition of wastewater. Lamb (10) referred to one or two cases where biological slimes caused increased head loss of fine bubble tube diffusers but no details were given.

In 1980, Houck and Boon (11) carried out an extensive survey of 19 wastewater treatment plants in the United Kingdom, the Netherlands, and the U.S. that employed fine bubble dome diffuser aeration devices. The major objective of this work was to assess long term oxygen transfer performance and operation and maintenance history of dome diffuser aerators. As a part of this study, the authors reported that the major operational problem associated with dome diffusers was the formation of biological slimes on diffusers operating in zones of high volumetric loading and/or low dissolved oxygen. In only two cases, however, were domes observed to contain excessive amounts of biological slime (Beddington, U.K., and Madison, WI). All other plants apparently exhibited signs of "coarse bubbling" which the authors attributed to the development of biological slimes. The authors further cited pilot plant work at the Water Research Centre at Stevenage, U.K. which verified the causes of diffuser sliming as the result of very high loading rates (12). No data was presented, however.

Madison, Wisconsin observed a severe biological sliming problem in the early part of 1980, about two years after installation (13). Heavy infestations of stalked ciliates (predominantly Epistylis) were observed on the dome surfaces and the plastic air piping. Slime cover on the domes was not uniform, completely covering some domes while being almost absent on other adjacent domes. It appeared that slightly more growth occurred on domes in the first pass and less in the third pass of this step aeration system. This plant experienced high BOD loading throughout the first half of 1980, the predominant source being several dairies in the community. Prior to this heavy loading period no apparent heavy slime growth was noted on the diffusers when the tanks were dewatered. Following the high loading period in early 1980, the domes were steam cleaned in-place and returned to service. Since that time, the domes have been periodically checked. Some slime growth has reappeared but it contained few stalked ciliates and was more diverse in biological population. The slime was easily removed with high pressure water hoses. Since the high load incidence, in 1980, there has not been a recurrence of the heavy biological slime formation at the plant.

Biofouling Agents

Over the years, several investigators have analyzed the biological slime that developed on fine bubble diffusers. A synopsis of these findings appears in Table II. In most cases when biological slimes were found, no specific identification was provided but descriptions of color or consistency were given.

TABLE II. BIOFOULING AGENTS

Agent	Source
Worms - Tubifex, Aulophorus	[Setter (7), Madison (13)]
Iron bacteria - Crenothrix	[Setter (7)]
Stalked ciliates - Epistylis	[Setter (7), Madison (13)]
Filamentous bacteria	[Setter (7)]
Fungii - Saprolegnia	[Anderson (9)]
"Biological slime"	[Roe (2), Wisley (6), Op & Cont.(5), Lamb (10), Houck & Boon (11)]

The occurrence of Epistylis (species undetermined) as a predominant organism in the biological slime on the domes at Madison, Wisconsin was interesting. Further investigation of the heavy plant loads during the severe bioslime incidence, indicated that an unusually high amount of dairy wastewater including whey was discharged during that period (13). Metabolic studies with Epistylis have indicated that this attached ciliate, unlike many others, may feed on inert wastewater nutrients as well as bacteria (14). Whether the presence of specific nutrients in the dairy waste promoted the unusual bloom of Epistylis and subsequent formation of heavy slime growths on the ceramic diffusers or whether the presence of this organism was incidental to the real causative agent in the bioslime at Madison is uncertain. The almost complete absence of Epistylis in subsequent biological slimes at Madison suggests that the waste characteristic itself (rather than organic load or low dissolved oxygen) may have played a predominant role in the development of serious bioslimes on the diffusers at that plant.

Causes of Biofouling

The published literature does not contain any report of a controlled study on the causes of bioslime development in activated sludge diffused air systems. Most hypothesis have been based on observations at operating plants. The major causes of biofouling that have been proposed based on field experience are presented in Table III. Roe (2, 15) indicated that quite often a film of biological growth appeared on the diffuser surface and even grew into the pore structure of ceramic diffuser plates. He indicated that poor air distribution within the plate resulted in biological growths along and within the quiescent pore spaces. Lamb (10) speculated that these slimes appeared after the pores of the diffuser had become clogged by dirt from the inside or incrustation from the outside. Setter (7) proposed that biological clogging became more severe as the BOD loading increased and as the permeability of the plates decreased. He also suggested that sufficient air flow rate per diffuser should be maintained in order to avoid excessive biofouling. Both Setter (7) and Anderson (9) suggested that biological clogging appeared to be seasonal. Heaviest fungal growths were found to occur during the summer months (9).

TABLE III. CAUSES OF BIOFOULING

- Uneven air distribution in diffuser (2, 7, 10)
- Low air flow rate per diffuser (7)
- High organic loading (7, 11)
- High temperatures (7, 9)
- Low dissolved oxygen concentration (11)
- Low permeability of diffusers (6, 7)
- Waste characteristics

The field study of 19 diffused air plants conducted by Houck & Boon (11) provided additional data on bioslime formation. These investigators claimed that the formation of biological growths on dome diffusers was the result of high organic load and/or low dissolved oxygen. They speculated that the growth was exacerbated by extreme plug flow aeration tank design. Boon and Burgess (12) also reported heavy slime growth development on dome diffusers in pilot plant studies using organic loads to a first stage aeration tank of up to 420 lb BOD_5/1000 ft.^{3}/day.

Similar excessive slime growth problems reported for the activated sludge plant at Madison occurred during high organic load conditions. A synopsis of the data collected at Madison prior to and following this biofouling incident is presented in Table IV. Several interesting points should be emphasized regarding this and other studies. The organic loads (expressed as lb BOD_5/1000 cu ft/d) to the Madison plant prior to heavy biofouling averaged about 20. During the heavy load period, the average rose to about 35 and subsequently dropped after the first six months of 1980 to about 29 where it has remained. Only during the heavy load period in the first six months of 1980 did a severe slime development occur. This was coincident with heavy dairy waste loadings including whey which were discontinued by mid year. At the time of this heavy slime infestation, the plant was being operated in a step aeration mode.

TABLE IV. DIFFUSER STUDIES - MADISON NINE SPRINGS PLANT

Aeration Tank Information:

Tanks 1-6 each 31' x 135' x 15.5' deep (2-3 pass tanks)
Diffusers: Ceramic Domes - Tapered Aeration
In Service: October, 1977

DATE	Mode of Operation*	F/M (LB/DLB)	BOD LOAD (LB/1000 FT^3/D)	OTE (%)	NOTES
10/27-12/77	CS	0.27	20.3	-	
1/78-6/78	CS	0.29	22.3	14	Dewater tanks - diffusers OK
7/78-12/78	CS	0.25	17.2	18	
1/79-6/79	CS	0.23	19.2	-	
7/79-12/79	S/CS	0.37	25.5	-	
1/80-6/80	S	0.34	34.6	7.5-8	Dewater tanks - heavy slime
7/80-12/80	S	0.34	29.2	8-10	Steam cleaned diffusers Dewatered - moderate slime Steam cleaned diffusers
1/81-6/81	S	0.33	30.1	-	Dewatered - moderate slime
7/81-11/81	S	0.39	30.4	16	OTE by off gas

*CS - Sludge Reaeration in First Pass
S - Step Aeration

In contrast to this, the slime infested aeration tanks at the Beddington, U.K. works were only loaded at 11 lb BOD_5/1000 cu ft/day but the plant did receive heavy industrial waste loadings. Other plants surveyed by Houck & Boon (11) experienced loadings ranging from about 10 to over 110 lb BOD_5/1000 cu ft/d. Some of these plants experienced coarse bubbling, but no severe sliming problem was reported (all diffusers likely were coated with some biological material but the authors did not present quantitave evidence of severe fouling). A review of operating records at the Milwaukee Jones Island West Plant during the years 1952-66 (16) indicated BOD loadings averaging 60 lb BOD_5/1000 cu ft/d. This plant received substantial amounts of industrial waste. No severe biofouling incidences have been reported for the ceramic plates at this plant during that time although incrustations and rust contributed to clogging problems.

The point to be made from this scant information is that biofouling is apparently highly plant and waste specific. No generalizations may yet be made in reference to specific causes of severe biofouling. The Madison experience strongly suggests that their problem was waste specific and intermittent (not unlike the problem of sludge bulking in many plants); the problem at Beddington, on the other hand, is endemic, but, again, is likely due to plant and waste specific characteristics.

The Effects of Biofouling

The development of a biological growth on diffuser media could have several effects on diffuser performance. One might develop the following sequence of events that would occur as the biofilm developed.

> As air passes through the media, biological growths begin to develop along the media where little air passes (e.g., over the finer pores). This mat continues to develop and begins to overlap regions where air is escaping. The presence of the bioslime leads to bubble coalescence along the media. The effect of this progressive clogging might produce little noticeable change in DWP unless the biological slime envelopes the entire media surface. Under these conditions, the uniformity of the air released from the diffuser may be detrimentally affected and poor distribution may result. The OTE may decrease as bubble coalescence occurs and there could be visible changes in bubble patterns and the appearance of "coarse bubbling" at the surface. This type of diffuser clogging may not be evident as routinely measured by air line pressure losses or demand for more air (as a result of some loss in transfer efficiency). The biological slime may fluctuate in thickness and extent with season. Its net effect may not be serious depending upon the extent of slime development.

Other mechanisms of biological clogging may also occur as well as the one outlined above. Several investigators have speculated that biofouling occurs after or simultaneously with internal clogging or external encrustation. For such a situation, the following scenario might take place.

> Since porous media represents a distribution of pore sizes, air will initially flow through the coarser pores first where

resistance to flow is the lowest. Particulates in the air or chemical encrustations could begin to lodge within the larger pores forcing air to the next smaller pore size. This would result in the progressive utilization of the finer pores producing, perhaps, more uniform distribution and finer air bubbles. Increases in DWP could be small at this point. As time progresses, the next size pores could begin to fill, eventually resulting in the utilization of the finest pore openings. As the effective cross-section through which air passes is restricted, finer bubbles may form and dynamic wet pressures would increase to a point where significant air line losses would be detected. Heavier biological growth would begin to develop in the quiescent regions at the diffuser. Eventually the biological mat may result in bubble entrapment and coalescence. The net effect of this progressive clogging might be an increase in OTE up to a point (as air distribution improves and bubble size decreases) followed by a drop in OTE as coarser bubbles begin to form. Dynamic wet pressures would slowly rise to a point where only the finer pores are carrying air; after this, pressures would rapidly rise. At this stage, depending upon diffuser shape and general design considerations, coarse bubbles may form or major short circuiting of air past gaskets or around bolts may occur. At these high air flow rates per unit area, a continuous stream of bubbles may be discharged from these locations and the diffuser would no longer behave as a fine pore device. Surface tension would no longer be measureable and the area would act like a very large pore. DWP would not change at this point and the major effect would be a substantial loss in OTE as the behavior of the device approached that of a coarse bubble diffuser. In another case, where no outlet for air flow is available within the diffuser element, the extent of fouling could be such as to severely restrict flow to a point where DWP (and BRP) rapidly increased to a point where significant air line pressures would require diffuser cleaning.

Presently, there is not a great deal of evidence to support either of these hypotheses of progression of biological clogging. Historically, the literature indicated that biofouling normally produced little change in DWP. Isolated incidences at Madison and Beddington, U.K. suggested that severe biological slime development produced dramatic changes in DWP and BRP. An example of the effects of heavy biofouling of a ceramic dome at Madison is presented in Figures 2-5. In this example, it is seen that the DWP at 0.75 SCFM increased from about 6 inches to about 18 inches after severe clogging (Figure 2). BRP values on the top side of the dome increased from about 6 inches of water to a range of 14 to 10 inches after bioslime development (Figure 3). There was a slight increase in BRP on the bottom side of the dome increasing from about 6 inches to 7.5 inches (Figure 4). It was clear that in this case, the bioslime produced the major resistance to air flow. Note in the air flow profiles of Figure 5, the majority of the air passed out along the periphery of the center bolt washer and the edges of the dome once a clogging mat had developed within the main body of the dome. Even when new, the air flow profile suggested that air distribution was not ideal

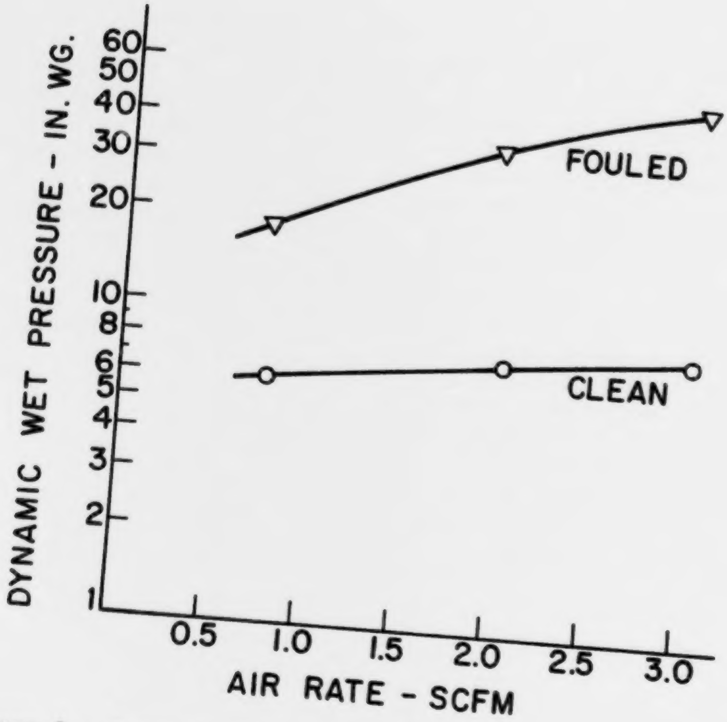


Figure 2. Dynamic wet pressure for clean and clogged dome - Madison,WI.

but once clogging was initiated, the biological slime exacerbated the air flow distribution producing excessively high rates in very localized regions. It is likely that this condition led to severe reductions in OTE, but no data is currently available to substantiate this under properly controlled conditions.

Of significant interest in diffuser fouling phenomenon is the impact of the slime on OTE. Results from Madison (Table IV) suggest that the severe biofouling of the domes produced dramatic reductions in OTE. Once cleansed, these diffusers appeared to essentially return to their original high level of efficiency. It should be carefully noted, however, that the field OTE measurements made at Madison were crude, at best. Early measurements were made during the sludge reaeration process whereas later measurements were made in the aeration tanks when operated as a step aeration process. Differences in alpha could have strongly influenced the comparison of these data.

The phenomenon referred to as "coarse bubbling" has been used as a visual indicator of diffuser biofouling (11). In some instances, this deduction has been shown to be correct. There are other cases, however, where the incidence of "coarse bubbling" may be due to other factors. These authors have had the opportunity to visit several plants where "coarse bubbling" occurred intermittently. The coarse bubbles were most noticeable at the influent end of the aeration tanks and would appear and disappear

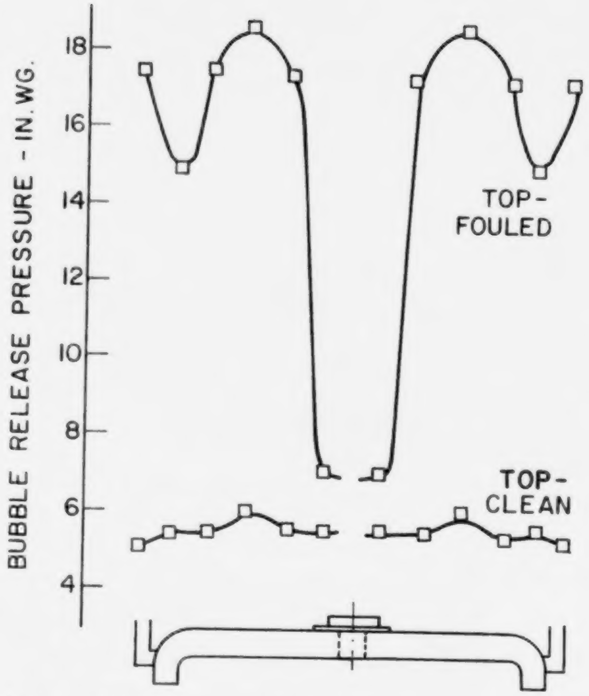


Figure 3. Bubble release pressures for the top of a clean and clogged dome - Madison, WI.

throughout the day. No diffuser sliming was noted at these plants. Currently, it is believed that coarse bubbles may occur as the result of the presence of high surfactant concentrations. Poorly mixed influent with mixed liquor may produce zones of high surfactant concentration with concomitant low surface tension. These zones may fluctuate as waste flow and characteristic change, but would be most noticeable at points of waste influent flow.

The response of different types of diffuser materials and shapes to biofouling is not well documented. At Madison, those aeration tanks equipped with ceramic and plastic tube diffusers did not experience the severe biofouling problem that was prevalent in the ceramic dome aeration tanks. The waste load to all the tanks was similar and tank geometry was approximately the same. Presently no explanation is available for these observed differences.

Design for Biofouling Control

Until better information is available on the causes of biofouling of fine bubble diffusers, it is difficult to delineate specific design criteria to control the process of biological fouling.

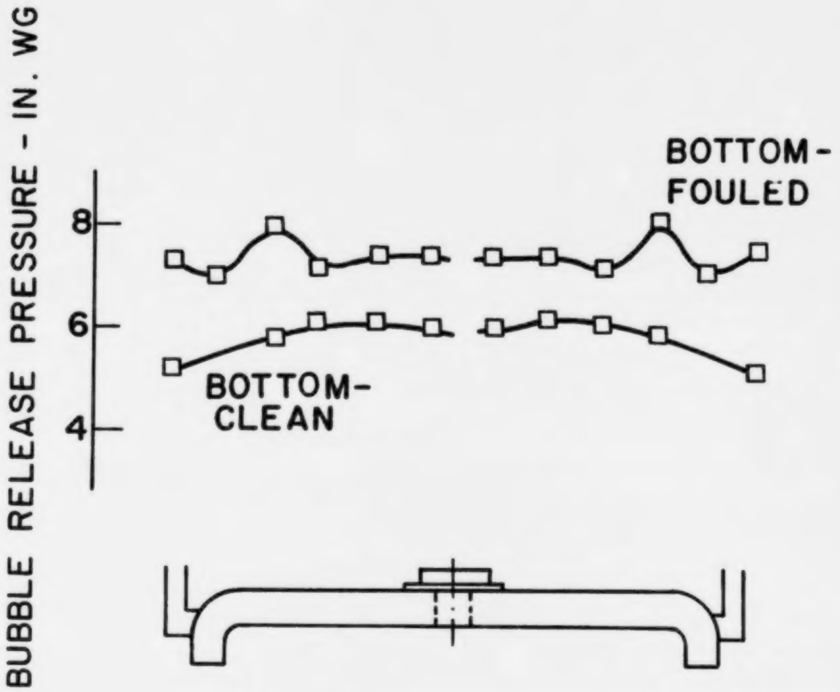


Figure 4. Bubble release pressures for the bottom of a clean and clogged dome - Madison, WI.

There is a certain amount of field evidence that suggests that the design of the diffuser element itself is important in preventing extreme fouling problems. Uniform distribution of air throughout the media would seem to be of paramount importance. Furthermore, it is quite likely that there is a minimum air flow rate per diffuser that is required to prevent encroachment of bioslimes on the diffuser surface. Herein lies one dilemma with diffuser design since low air flow rates normally produce higher OTE and there is a temptation to size aeration facilities to favor better transfer efficiencies. Unfortunately, the placement of high diffuser densities (and concomitant reduced air flow rates per diffuser) in an aeration tank to take advantage of the more favorable transfer efficiencies may eventually lead to maintenance problems and eventual loss of efficiency due to biofouling. More data needs to be collected to corroborate this reasoning, however.

The clean water testing of fine bubble diffusers is most often used by engineers to size aeration systems for dirty water testing. Although engineers attempt to account for this translation through the use of an alpha correction, little thought has been given to changes that may occur in diffuser properties once placed in the dirty water over a period of time. BRP measurements made on selected diffusers removed from operating plants suggest that air flow distributions may be significantly changed. This may produce substantial changes in OTE, not accounted for in the clean to dirty water

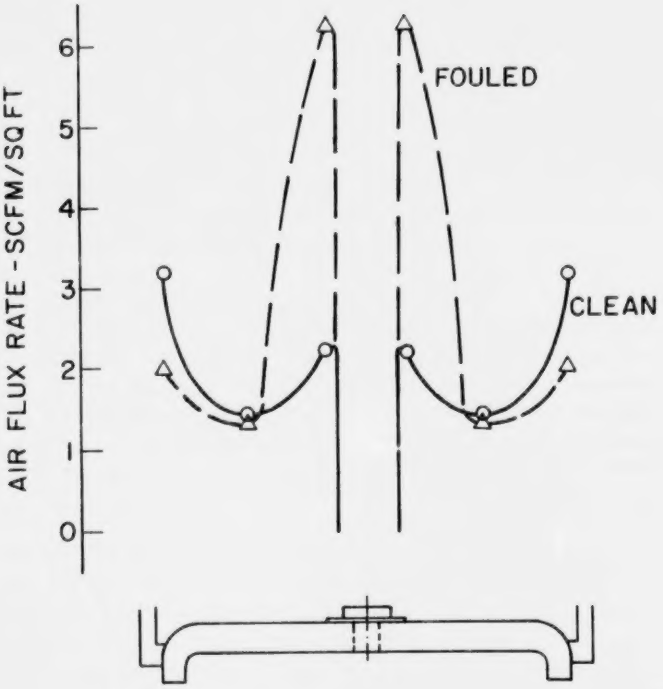


Figure 5. Air flux rate for a clean and clogged dome - Madison, WI. (Average flux rates for concentric circles.)

translation.

Houck and Boon (11) recommended that aeration tanks be designed to avoid excessively high localized organic loading which might lead to fine bubble diffuser clogging. They recommended the use of low length to width ratios, step feeding and tapered aeration as means to reduce potential clogging problems. Another approach would be to employ a coarse bubble or mechanical aeration system at the influent end of plug flow systems. The loss in efficiency may be well worth the decrease in diffuser maintenance.

There has been considerable interest generated recently in the in situ cleaning of fine bubble diffusers including internal gas cleaning as well as mechanical jetting, steaming or brushing. In any event, aeration tanks employing full floor coverage units should employ some type of rapid tank draining facility.

If biological fouling is considered to be primarily the result of the wastewater characteristics, pretesting of selected diffusers in that wastewater may be highly desirable. The installation of a test fixture employing two or more diffusers within an existing aeration tank has provided very useful information on diffuser clogging potential of selected wastewaters (17). A test fixture instrumented in a fashion similar to that in Figure 1 was used. DWP measurements made over a two to three month period provided useful data on clogging potential. Laboratory follow up analyses on individual diffusers provided additional data on air flow distribution and BRP thereby providing a sensitive indicator of the relative degree and progression of clogging.

BIOFOULING - FUTURE RESEARCH

The impact of long-term fine bubble diffuser operation in wastewater with respect to maintenance requirements and OTE is still poorly documented. It is clear that some biological growth will develop on diffuser surfaces but the impact of that growth on performance is unclear. Research should be directed under controlled experimental conditions toward measuring the progression of biological fouling employing sensitive BRP and air flow distribution techniques. These studies should include a variety of diffuser materials and geometry. The selection of diffuser systems is often predicated on the performance of clean diffusers in clean water. The long term changes in OTE during diffuser operation in wastewater should be more clearly delineated in order to provide the engineer with a clearer picture of what happens to OTE over the design life of the diffuser.

As energy costs continue to escalate, engineers will seek more effective energy conserving systems for the transfer of oxygen to wastewater. Until a better understanding of the behavior of fine bubble diffusers under long-term field conditions can be delineated, doubts will continue to be raised regarding the effectiveness of the fine bubble system. Furthermore, misapplication of these systems in certain situations may result in a greater expenditure of manpower and energy than would be estimated.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the cooperation and assistance of Mr. Paul Nehm and Mr. Tim Weir of the Madison Metropolitan Sewerage Commission. Their contributions to a better understanding of biofouling are greatly appreciated. We also acknowledge the assistance and counsel of Mr. Jerry Wren, of Sanitaire-Water Pollution Control Corp, Milwaukee.

REFERENCES

1. Wesner, G. M., et al. Energy Conservation in Municipal Wastewater Treatment. EPA 430/9-77-011; Office of Water Program Operations; U.S. EPA; March, 1978.
2. Roe, F. C. The Installation and Servicing of Air Diffuser Mediums, Water and Sew. Wks, 81:115, 1934.
3. Beck, A. J. Diffuser Plate Studies, Sew. Wks. Jour., 8:22, 1936.
4. Committee on Sewage Disposal. The Operation and Control of Activated Sludge Sewage Treatment Works, Sew. Wks. Jour., 14:3, 1942.
5. Bushee, R. J. and Zack, S. I. Test on Pressure Loss in Activated Sludge Plants, Eng. News Record, 93:21, 1924.
6. Wisley, W. H. Summary of Experience in Diffused Air Activated Sludge Plant Operation, Sew. Wks. Jour., 15:909, 1945.
7. Setter, L. R. Air Diffusion Problems at Activated Sludge Plants, Water & Sew. Wks., 95:450, 1948.

8. Setter, L. R. and Edwards, G. P. Experimental Laundering of Air Diffuser Plates, Sew. Wks. Jour., 17:867, 1945.
9. Anderson, N. E. Tests and Studies on Air Diffusers for Activated Sludge, Sew. and Ind. Wastes, 22:461, 1950.
10. Lamb, M. Designing and Maintaining Porous Tube Diffusers, Wastes Engineering, 25:405, 1954.
11. Houck, D. H. and Boon, A. G. Survey and Evaluation of Fine Bubble Dome Diffuser Aeration Equipment. EPA 600/S2-81-222; Municipal Environ. Research Lab; U.S. EPA; Oct. 1981.
12. Boon, A. G. and Burgess, D. R. Treatment of Crude Sewage in Two High Rate Activated Sludge Plants Operated in Series, Water Poll. Control, 73:382, 1974.
13. Nehm, P. History of Norton Dome Fine Bubble Diffused Aeration at MMSD. An Internal Report to MMSD, July 1981.
14. Pillai, S. C. and Subrahmangan, V. The Role of Protozoa in Aerobic Purification of Sewage, Nature (London), 154:179, 1944.
15. Roe, F. C. Sewage Aeration by Diffused Air, Sew. Wks. Jour., 5:813, 1933.
16. Leary, R. D., Ernest, L. A. and Katz, W. J. Effect of Oxygen Transfer Capabilities on Wastewater Treatment Plant Performance, Jour. Water Poll. Cont. Fed., 40:1298, 1968.
17. Wren, Jerome; Personal Communication; Sanitaire-Water Pollution Control Corp., Milwaukee, WI, 1981.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

SESSION NO. 3
Improving Process Reliability

PAPER NO. 9

STABILITY AND RELIABILITY OF BIOLOGICAL PROCESSES

by

E. D. Schroeder

and

Salar Niku

Department of Civil Engineering
University of California, Davis
Davis, California 95616

STABILITY AND RELIABILITY OF BIOLOGICAL PROCESSES

E.D. Schroeder and Salar Niku
Department of Civil Engineering
University of California, Davis
Davis, CA 95616

Biological wastewater treatment processes are treated by designers, operators and regulators as steady state processes that do not fail. The same designers, operators and regulators fully recognize that these systems experience wide ranges of loading, and environmental parameters, and that the systems often do fail. Despite this knowledge process design is based on steady state assumptions, whether a kinetic or a loading factor approach is used, and operation is based on the same approach. It is an accepted fact that biological treatment processes are not completely stable or reliable but present deterministic and conceptual models so not come close to providing adequate descriptions of process behavior. The principle factors that are missing are satisfactory dynamic models that incorporate hydrodynamic coupling and knowledge of actual stochastic variation in process performance. The purpose of this paper is to discuss results of a study in which daily data from 43 activated sludge and 11 trickling filter plants was analyzed. Previous reports based upon this study will be summarized and the work will be extended to applications in design, operation and regulation (1, 2, 3, 4, 5).

Probabilistic Approaches To Process Analysis

Statistical methods have been used to correlate process variables for a very long time. An early example is the NRC report (6). In this study mean effluent BOD_5 and suspended solids values from trickling filter plants at 34 military installations were used to develop removal efficiency relationships (the NRC formulas). The mean values used were based on monthly values and for periods varying up to 20 months. The relationships developed were statistically weak, even assuming that comparison of the data populations was appropriate (7). Other studies of one or a few plants have resulted in expressions for predicting process performance (8,9) but the expressions have not been widely accepted.

More recently work has been directed at determining the variation in effluent quality and process performance (10,11,12,13,14,15). With the exception of Hovey et al. work (15) the previous studies were based upon a large amount of data from one or a few plants within a limited geographical region. Hovey et al. considered annual data for a one year period from 28 plants some of which are included in this study. Most of Hovey et al's plants were in California, but a few were from the Midwest. A general conclusion of these workers was that a log-normal distribution provided the best fit to the data. Hovey et al. did not find a generally satisfactory probability density function but did find excellent correlation between the effluent characteristics percentile (i.e. the percentile value of a given concentration value) and the annual mean for individual plants. A similar result had previously been reported by Townshend (16).

Considering the number of physical and environmental variables affecting wastewater treatment plant performance it is unlikely that a particular model, deterministic or stochastic, will fit every situation. Variation in effluent quality would be expected to have a log-normal component because the effects of many variables are linked together multiplicatively. Thus it is not surprising that previous workers have found good log-normal fits to their data and that in this study the log-normal distribution could be rejected in only 13 of the 43 cases.

Use of Distributions

When a distribution has been established a number of useful relationships can be developed. These include determination of the probability that a given plant can meet a particular discharge standard (reliability), the relative range of product quality with respect to discharge standards and/or the mean value from the process (stability) and the effect of selected variables (eg. temperature) and process parameters (eg. overflow rate/design overflow rate) on process performance. These determinations were done for the plants studied and the results are summarized below:

Process Reliability

In considering the reliability relationships developed it should be remembered that the plants used in this study were chosen because they were believed to be well operated and sources of good data. Thus the reliability relations should be appropriate for use in design and as measures of expectation. As stated above reliability is the probability that a chosen standard (eg. 30 d average $BOD_5 \leq 30$ g/m^3) will be met.

Construction of reliability model requires that a distribution function be chosen. Because it provided the best overall fit the log-normal distribution was chosen. It is also desirable to have a model stated in arithmetic rather than log terms. For this reason the effects of the log-normal distribution were incorporated into a single parameter, the coefficient of reliability (COR) that relates the chosen standard, X_s, to the mean effluent value, m_x, required to meet the standard a given fraction of the time.

$$m_x = (COR)X_s \qquad (1)$$

That is if the standard X_s is to be met a given fraction of the time the actual process mean effluent value must be m_x. The theoretical COR value is derived from the log-normal distribution probability density function.

$$(COR) = \frac{m_x}{X_s} = (V_x^2 + 1)^{1/2} \exp\{-Z_{1-\alpha}[\ln V_x^2 + 1]^{1/2}\} \qquad (2)$$

$$Z_{1-\alpha} = -\frac{\ln \frac{m_x}{X_s}(V_x^2 + 1)^{-1/2}}{[\ln(V_x^2 + 1)]^{1/2}} \qquad (3)$$

where V_x = coefficient of variation = σ_x/m_x

$Z_{1-\alpha}$ = standard normal variate

σ_x = arthmetic standard deviation

Values of the COR are given in Table 1 for selected values of V_x and percent reliability, and the relationship is presented in graphical form in Figure 1.

Use of equation (1) for design, operation or regulation requires some knowledge of "reasonable expectations." The first step is to verify that the COR values developed from the log-normal distribution can be used to predict actual process performance. Verification requires comparison of the predicted reliability based on measured values and Table 1 or Figure 1 with calculated reliability from data. Results are given in Tables 2 and 3 for activated sludge and trickling filter plants respectively.

Process Stability

Stability is often used in a qualitative sense or with respect to a particular situation. A quantitative definition of stability must reflect the commonly understood definition to be accepted and useful. Two general approaches might be used. First the occurrence of upsets might be cataloged and stability defined in terms of number of upsets per year or the ratio of upset days to non-upset days. This approach is only quasi-quantitative because the definition of "upset" is qualitative. Additional problems result from the facts that activated sludge plants are generally termed upset only when effluent suspended solids are high, a visually observable situation and attached growth process behavior is quite different than suspended growth systems. A second approach is to define a parameter as a measure of stability. Suggested parameters include the standard deviation, S_x, coefficient of variation, V_x (ratio of standard deviation to mean) and coefficient of stability, COS (ratio of variance to mean). Both ratios suffer from the fact that processes with a low mean value can have the same coefficient as ones with high mean values. For example a plant with mean effluent mean and standard deviation values of 6 and 3 g/m^3 respectively, will have the same coefficient of variation as a plant with mean and standard deviations of 50 and 25 g/m^3.

Standard deviation was chosen as the basic stability parameter in this study because a definite, unnormalized measure of dispersion is provided and because it is a widely understood term. Further support for the choice was provided when strong correlations between the standard deviation and the mean annual maximum value and the COS were found (Table 4). By itself stability is only a relative parameter, that is the larger S_x the less stable the plant. A reference value or cut off point is needed that divides plants into unstable and stable groups. This was done arbitrarily after plotting mean and range vs standard deviation (Figures 2-5). Both range and mean tend to have higher values for plants with standard deviations greater than 10 g/m^3 as either BOD$_5$ or SS. The effect is quite pronounced with activated sludge plants (Figure 2 and 3) and less so with trickling filters (Figures 4 and 5).

Outliers: Inclusion of range (or maximum value) as a factor in defining stability forces consideration of outliers: single points that greatly deviate from the general

TABLE 1. COEFFICIENT OF RELIABILITY[a] AS A FUNCTION OF V_X AND RELIABILITY FROM POOLED PLANT DATA

Row 1 for BOD, Row 2 for SS

Reliability	50%	80%	90%	95%	99%	100%
V_X						
0.3	1.08	0.85	0.74	0.64	0.50	0.39
	1.08	0.87	0.75	0.66	0.49	0.34
0.4	1.11	0.80	0.68	0.57	0.43	0.32
	1.11	0.84	0.70	0.59	0.42	0.27
0.5	1.14	0.77	0.63	0.51	0.38	0.27
	1.15	0.80	0.65	0.53	0.36	0.23
0.6	1.17	0.73	0.58	0.46	0.34	0.24
	1.18	0.77	0.61	0.49	0.32	0.20
0.7	1.20	0.70	0.55	0.43	0.30	0.21
	1.22	0.74	0.57	0.45	0.29	0.17
0.8	1.24	0.67	0.51	0.39	0.28	0.19
	1.26	0.72	0.54	0.42	0.26	0.15
0.9	1.28	0.65	0.48	0.37	0.25	0.17
	1.30	0.69	0.51	0.39	0.24	0.14
1.0	1.32	0.62	0.46	0.34	0.23	0.16
	1.35	0.67	0.48	0.36	0.22	0.13

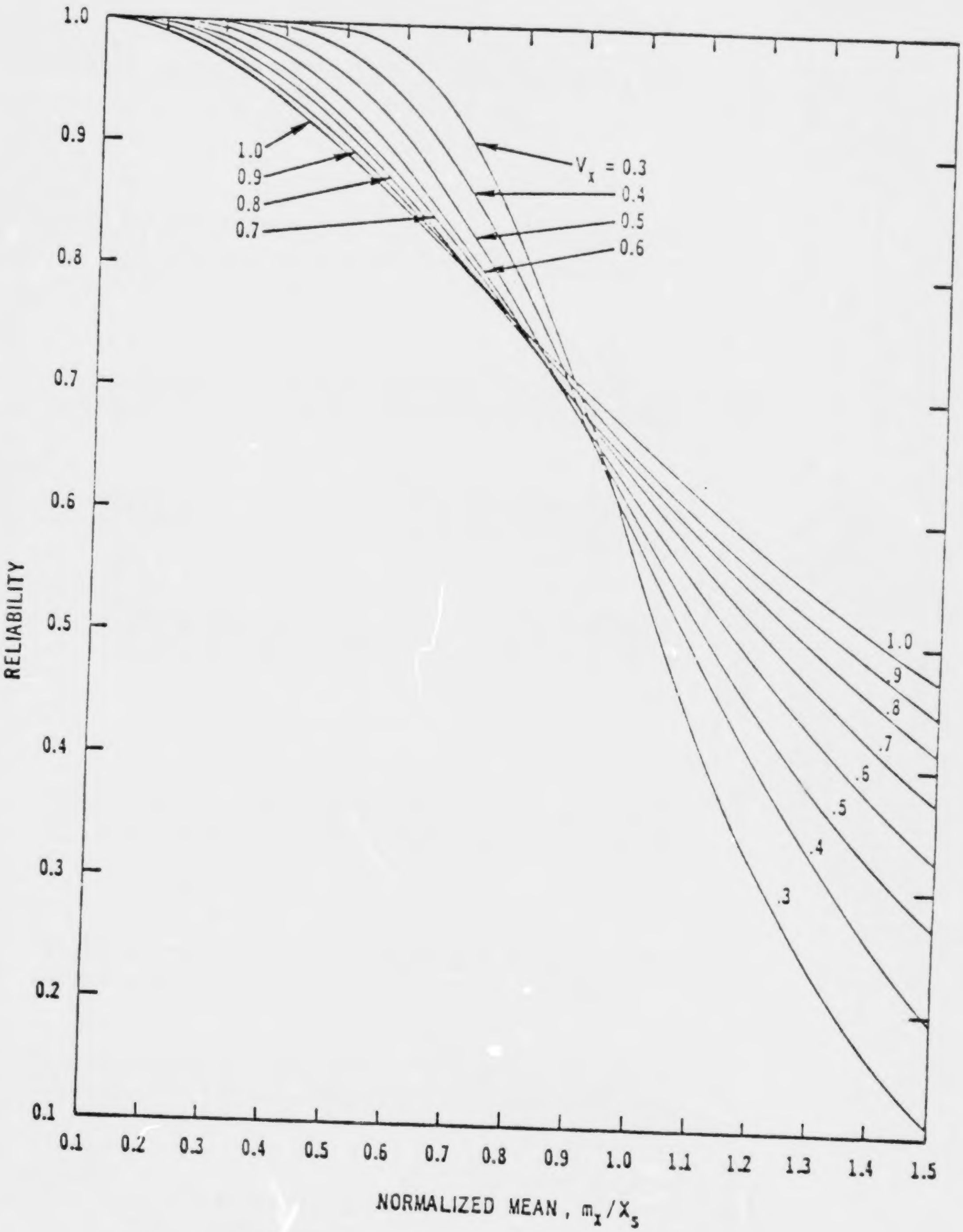


Figure 1. Reliability versus normalized mean for different coefficients of variations.

TABLE 2. COMPARISON OF PREDICTED AND MEASURED PERFORMANCE OF ACTIVATED SLUDGE PLANTS ACROSS THE UNITED STATES

	BOD				SS			
			%time < 30 g/m^3				%time < 30 g/m^3	
Plant Number	V_X	$\bar{X}/30$[a]	Predicted	Measured	V_X	$\bar{X}/30$	Predicted	Measured
1	0.75	0.33	97.10	99.1	1.17	0.37	93.80	96.2
2	0.52	0.28	99.80	100.0	0.43	0.21	>99.99	100.0
3	0.67	0.33	98.30	97.8	0.32	0.48	99.40	100.0
4	0.62	0.61	87.50	87.9	0.83	0.87	71.10	75.5
5	0.57	0.54	92.30	91.2	0.74	0.71	80.20	85.5
6	0.56	0.55	92.60	91.4	0.73	0.73	78.10	83.3
7	0.54	0.71	82.40	86.5	1.27	0.56	86.00	89.9
8	0.99	0.55	87.20	91.5	1.26	0.70	80.40	86.1
9	0.91	0.83	73.50	70.3	0.98	1.48	52.70	58.0
10	0.38	1.01	56.30	60.1	0.32	1.96	2.30	3.1
11	0.90	0.62	84.30	90.4	1.70	0.34	93.40	94.2
12	0.43	0.55	95.10	95.0	0.79	0.49	91.50	94.3
13	0.87	0.55	88.00	88.6	1.13	0.49	89.20	89.0
14	0.95	0.77	76.60	77.9	1.37	1.16	64.40	67.9
15	0.86	0.89	70.20	68.8	1.21	0.94	70.50	70.6
16	0.51	0.16	99.99	100.0	0.55	0.18	>99.99	100.0
17	0.72	0.06	99.99	100.0	1.13	0.09	>99.99	100.0
18	0.34	0.08	99.99	100.0	0.47	0.15	>99.99	100.0
19	0.42	0.16	99.99	100.0	0.48	0.27	>99.99	100.0
20	0.49	0.26	99.90	100.0	0.64	0.23	99.70	99.5
21	0.56	0.14	99.99	100.0	0.58	0.21	99.90	99.5
22	0.48	0.14	99.99	100.0	0.53	0.19	>99.99	100.0
23	0.58	0.10	99.99	100.0	0.56	0.12	>99.99	100.0
24	1.11	0.81	75.30	73.7	1.33	0.63	83.20	81.9
25	0.70	0.43	95.10	95.2	1.07	0.40	93.10	97.0

---

[a] $\bar{X}$ is the actual arithmetic mean value of the data (BOD or SS) in the plants.

TABLE 2 (continued)

Plant Number	BOD				SS			
			%time < 30 g/m^3				%time < 30 g/m^3	
	v_X	$\bar{X}/30$	Predicted	Measured	v_X	$\bar{X}/30$	Predicted	Measured
26	0.48	0.30	99.80	100.0	0.66	0.32	98.60	98.9
27	0.51	0.42	97.90	98.3	0.62	0.30	99.20	100.0
28	0.48	0.46	97.30	99.2	0.80	0.30	98.10	98.1
29	0.89	0.14	99.80	100.0	0.58	0.33	99.00	99.5
30	0.95	0.20	99.20	100.0	0.70	0.34	97.90	98.9
31	0.78	0.36	96.60	95.3	0.44	0.36	99.60	98.9
32	0.41	0.80	77.80	72.5	0.38	0.80	78.60	80.0
33	0.90	0.60	85.20	84.2	0.75	0.73	73.10	80.9
34	0.60	0.29	99.40	99.7	0.52	0.49	95.60	97.3
35	0.86	1.05	62.00	64.8	1.07	1.18	59.80	64.9
36	0.70	0.22	99.70	100.0	0.53	0.24	99.90	100.0
37	0.61	0.70	82.00	84.3	0.76	0.64	84.10	76.0
38	1.20	0.55	86.50	86.5	1.37	2.17	40.50	51.1
39	0.68	2.85	8.20	12.1	0.93	2.67	19.80	21.9
40	0.37	0.48	98.70	98.8	0.60	0.29	99.40	99.6
41	0.43	0.30	99.90	100.0	0.69	0.33	98.20	97.7
42	0.68	0.69	81.90	85.8	1.30	0.95	70.80	77.8
43	1.27	0.71	79.90	84.2	1.68	1.41	61.10	71.6

TABLE 3

COMPARISON OF PREDICTED AND MEASURED PERFORMANCE OF TRICKLING FILTER PROCESSES

	BOD				SS			
			%time $\leq$ 30 g/m^3				%time $\leq$ 30 g/m^3	
Plant Number	V_X	$\bar{X}/30$	Predicted	Measured	V_X	$\bar{X}/30$	Predicted	Measured
1	0.46	1.11	49.3	49.6	0.59	1.75	22.6	19.4
2	0.67	0.36	97.6	97.5	0.62	0.72	80.6	78.1
3	0.75	0.34	97.4	98.3	0.79	0.70	80.5	76.2
4	0.36	1.94	4.3	8.0	0.27	1.83	1.6	5.6
5	0.38	0.94	63.8	57.9	0.48	0.61	90.5	93.1
6	0.25	0.90	70.9	72.6	0.40	0.50	97.7	98.1
7	0.73	0.77	76.6	75.5	0.63	0.80	75.0	70.7
8	0.15	1.44	2.1	1.1	0.40	1.13	45.0	45.8
9	0.39	1.70	11.1	17.8	0.43	1.37	28.8	28.5
10	0.30	0.70	91.4	97.6	0.61	0.79	75.8	72.8
11	0.65	0.61	87.1	88.2	0.55	0.54	92.7	93.4

Predicted percentages represent areas under the normal probability curve $F(Z_{1-\alpha})$, where $Z_{1-\alpha}$ is

equal to: $$Z_{1-\alpha} = -\frac{\ln \frac{m_x}{X_s}(V_x^2 + 1)^{-1/2}}{[\ln(V_x^2 + 1)]^{1/2}}$$ See Reference 5 for details.

TABLE 4. PEARSON CORRELATION COEFFICIENTS[a], r, OF ANNUAL DATA FOR 43 ACTIVATED SLUDGE TREATMENT PLANTS[b]

	BOD						SS					
	X	S_X	V_X	Max	COS	Antilog (LnS_X)	X	S_X	V_X	Max	COS	Antilog (LnS_X)
X	1.00	0.92	0.19	0.80	0.74	0.17	0.81	0.67	0.30	0.56	0.50	0.34
S		1.00	0.53	0.94	0.94	0.43	0.82	0.82	0.54	0.74	0.72	0.60
V			1.00	0.61	0.74	0.78	0.38	0.64	0.71	0.66	0.71	0.72
Max				1.00	0.93	0.36	0.80	0.87	0.64	0.82	0.81	0.63
COS					1.00	0.58	0.75	0.87	0.68	0.83	0.84	0.72
X							1.00	0.88	0.34	0.81	0.75	0.34
S								1.00	0.65	0.97	0.97	0.58
V									1.00	0.71	0.74	0.80
Max										1.00	0.98	0.57
COS											1.00	0.61

[a] The Pearson correlation coefficient, r, for variables X and Y is defined as:[8]

$$r_{X,Y} = \frac{1}{n} \sum_{i=1}^{n} \frac{X_i - \bar{X}}{S_x} \; \frac{Y_i - \bar{Y}}{S_y},$$ giving the cross correlation between any two chosen plant variables, such as X = BOD and Y = SS

[b] All measurements are at 0.001 significance level

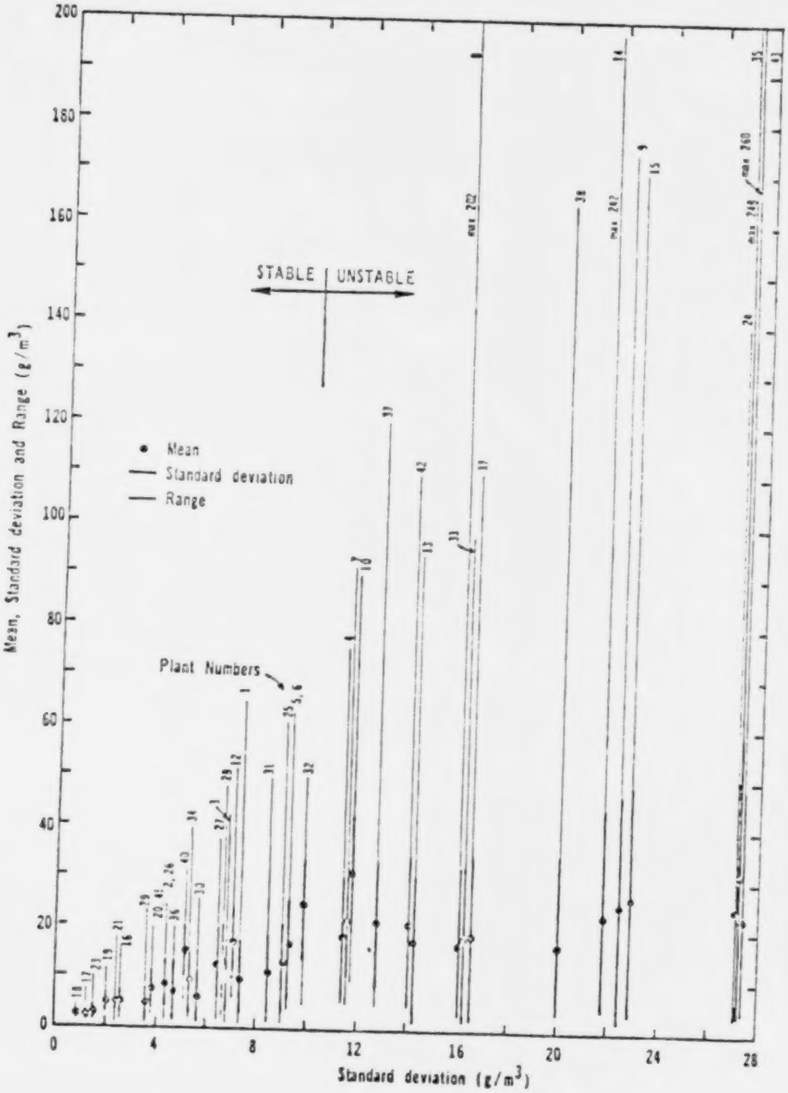


Figure 2. Mean, standard deviation, and range of effluent BOD concentration in different treatment plants.

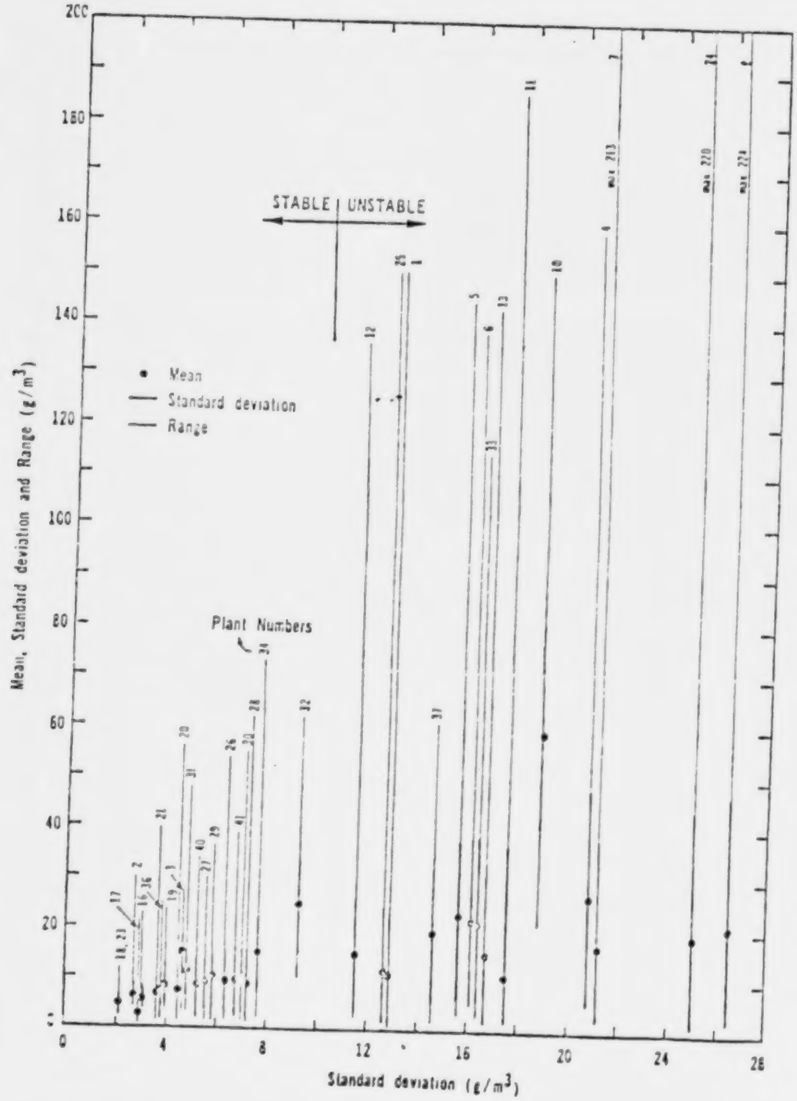


Figure 3. Mean, standard deviation, and range of effluent suspended solids concentration in different treatment plants.

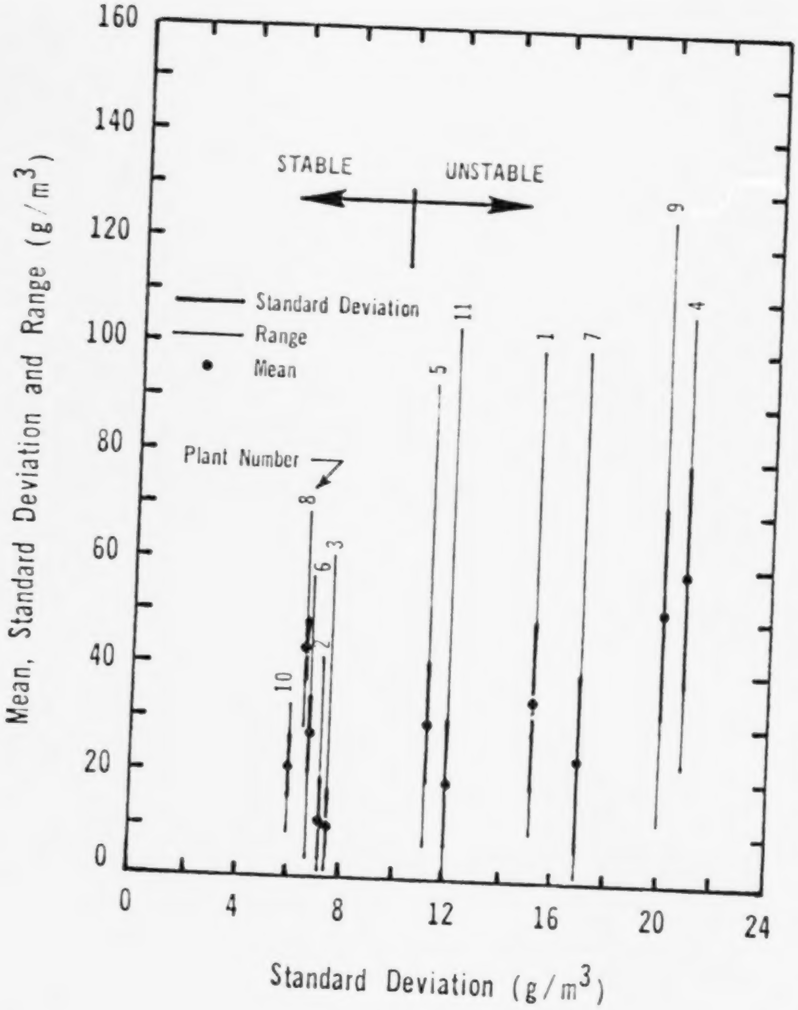


Figure 4. **Variability of effluent BOD as a function of standard deviation.**

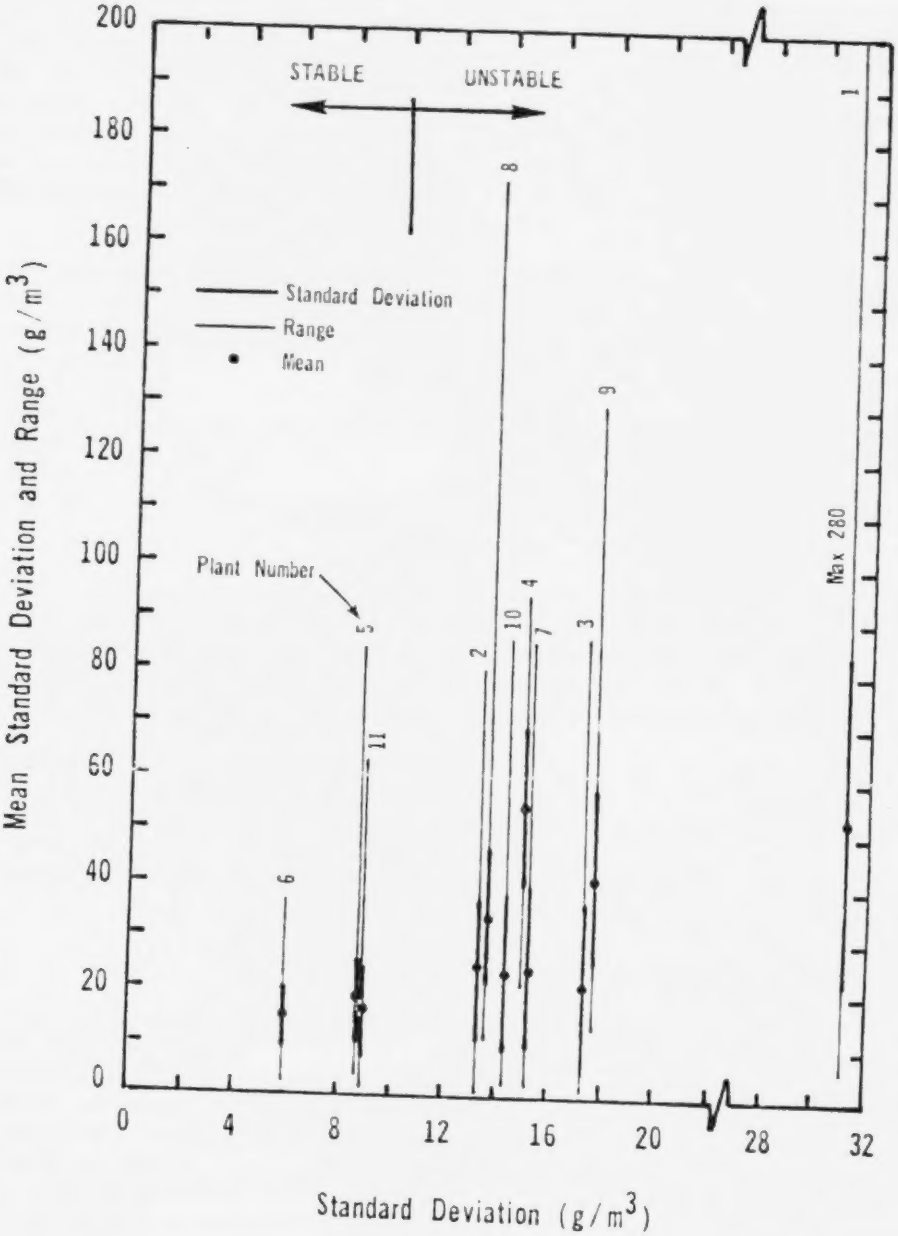


Figure 5. **Variability of effluent suspended solids concentration as a function of standard deviation.**

trend. These points often greatly effect or even dominate the standard deviation. For example a number of extreme values occur in the effluent BOD_5 data for both of the plants of Figure 6. Possible causes of the extreme values include mechanical failure, measurement error, introduction of toxicants, unusual weather and natural stochastic variation. If the cause is other than stochastic variation the points are true outliers and may be disregarded in determining the process characteristics. Removing the upper one-percent of data resulted in decreasing the standard deviations of the BOD_5 and suspended solids concentrations by an average of 1.6 and 3.6 g/m^3 respectively, but the relative stability ranking of the 43 activated sludge plants did not change.

Cyclic Patterns: It is well known that flow rates to municipal wastewater treatment plants tend to have weekly and seasonal cycles. Thoman (8), Adams and Gemmel (9) and Lin and Heinke (17) used spectral and harmonic analysis to remove non-random components from effluent data. They found significant weekly, seasonal and annual cycles. Similar cycles can be seen in Figure 6 for plant 10. In the 43 plants used in this study seven (10,14,15,24,29,30, and 35) were found to have significant cyclic patterns. Five of the eleven trickling filter plants exhibited significant weekly cycles and overall the BOD_5 and suspended solids concentrations tended to be below average on Sundays. Seasonal patterns were evident at all 11 trickling filter plants with improved performance in the summer.

Plant Configuration and Size: Seven types of activated sludge process were included in the study although most were either conventional or stepfeed systems. Results of considering annual statistics of each process type as a data population are given in Table 5. The results are interesting because for the four configurations with more than one representative there is a clear order of performance.

Plant size is also of interest because of trends toward construction of large regional facilities. The results of this study, which included plants with average flows ranging from less than 3000 to more than 750,000 m^3/d (0.8 to 200 mgd) are similar to those of Hovey et al. (12). No correlation between plant size and performance could be found. Thus improved performance does not appear to be a valid reason for regionalization.

Process Parameters and Variables

A number of parameters and variables were correlated with process performance using multiple regression analysis. These included wastewater temperature, time lag, flow, sludge volume index (SVI), mean cell residence time (MCRT), food to microorganisms ratio (F/M) mixed liquor suspended solids (MLSS), recycle solids concentration (X_r), recycle rate (Q_r), influent BOD and influent suspended solids. Twenty one of the 43 activated plants and all 11 trickling filter plants had sufficient data to allow evaluation of these parameters. Lag time refers to lagging input and output values in time to determine if processing time is a factor. Variation in a number of the variables and parameter correlated significantly with variation in effluent BOD_5 and suspended solids concentration but the pattern was not consistent. That is in some plants wastewater temperature was most important, in others influent BOD and in others flow rate was the principle factor. In general less than half the variation in effluent quality could be explained by the conbined effects of the process parameters and variables.

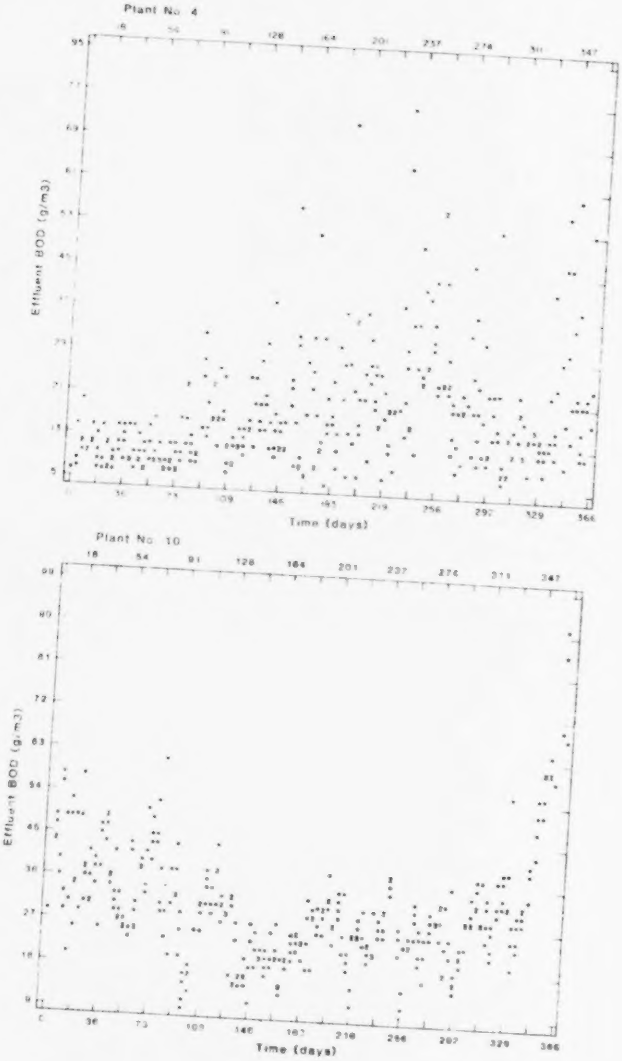


Figure 6. Typical time-series plots of effluent BOD and SS concentrations.

TABLE 5. STATISTICS OF THE ANNUAL EFFLUENT BOD AND SS CONCENTRATION DATA FOR DIFFERENT PROCESS TYPES

Process type	No. of plants	Mean		Standard deviation		Coef. of variation[a]	
		$\bar{X}$	S_x	$\bar{X}$	S_x	$\bar{X}$	S_x
				BOD			
Conventional	18	12.80	6.85	9.54	7.99	0.69	0.25
Complete-mix	5	16.82	6.67	13.24	6.51	0.77	0.13
Step-Feed/Aeration	13	10.84	7.68	8.28	7.56	0.68	0.25
Contact Stabilization	4	38.38	32.08	28.17	20.92	0.76	0.14
Extended Aeration	1	14.41	—	5.31	—	0.37	--
Kraus	1	24.02	--	9.85	--	0.41	--
Aerated Lagoon	1	30.35	—	11.61	—	0.38	--
All Plants	43	15.76	13.43	11.28	10.49	0.70	0.23
				SS			
Conventional	18	14.92	10.53	16.02	18.61	0.86	0.38
Complete-Mix	5	19.88	14.19	19.65	16.92	1.00	0.51
Step-Feed/Aeration	13	16.23	16.65	16.83	23.89	0.83	0.34
Contact-Stabilization	4	40.88	26.75	37.66	26.18	0.90	0.14
Extended-Aeration	1	8.82	—	5.28	--	0.60	--
Kraus	1	24.12	--	9.26	--	0.38	--
Aerated Lagoon	1	58.79	—	18.71	—	0.32	-
All Plants	43	19.40	17.03	18.35	20.60	0.84	0.37

[a] Average values from all plants, not calculated from parameter averages

Design and Operation Applications

The results of this study provide useful tools for both design and operation of biological wastewater treatment plants. The key relationships are Equation (1), Table 1 and Figure 1. It is important to recognize that a desired reliability must be chosen and that 100 percent reliability is impossible. Thus choosing a reliability value is the first step in application. The second step is consideration of the coefficient of variation (V_x). In general the higher the mean value the lower the estimated V_x. Because ensuring stability requires $\sigma_x = \leq 10$ g/m^3 the value of V_x is partially constrained. For example if a standard of 30 g/m^3 (BOD or suspended solids) is to be met 99% of the time and σ_x is to be maintained below 10 g/m^3 or less, the mean design (or operating) value is determined from a modified form of Table 1. As can be seen in Table 6 setting a reliability constraint of 99% results in required m_x and σ_x values that will be extremely difficult to meet.

Discharge standards now in general use are considerably less stringent than those of the above example because they are based on weekly and monthly averages. For a log-normally distributed population if the distribution of the means (weekly or monthly) has the same arithmetic mean and variance as the total population the geometric distribution of the means is also log-normal with a mean (m_{lnGM}) equal to the log of the population mean (m_{lnX}) and a variance, σ_{lnGM} equal to the population variance, σ_{lnX}, divided by the averaging period, n (1). Although discharge standards would be better stated in geometric terms (3) they are in fact stated as arithmetic averages. These can be related to the geometric values through Equation (4) and (5)

$$\sigma^2_{lnx} = \ln \frac{\sigma_x{}^2}{m_x{}^2} + 1 \tag{4}$$

$$m_{lnx} = \ln m_x - \frac{1}{2}\sigma^2_{lnx} \tag{5}$$

A population having an arithmetic mean and standard deviation of 30 and 10 g/m^3 respectively will have a log mean of 3.35 and a log standard deviation of 0.32. The 30 day log goemetric mean value and log geometric standard deviation values are then 3.35 and 0.058. These values can be used with Equations (6) and (7) to obtain the geometric mean and standard deviation.

$$\sigma^2_{GM} = m^2_{GM} \left(\exp \sigma^2_{lnGM} - 1\right) \tag{6}$$

$$\ln m_{GM} = m_{lnGM} + \frac{1}{2}\sigma^2_{lnGM} \tag{7}$$

Thus the population will have a geometric mean of 28.6 g/m^3 and a geometric standard deviation of 1.65 g/m^3. To have a 99 percent probability that the 30 day

TABLE 6: DESIGN M_x and σ_x FOR X_s = 30 g/m^3

V_x	99th Percentile COR	m_x	σ_x
0.3	0.53	15.9	4.8
0.4	0.44	13.2	5.28
0.5	0.37	1.1	5.6
0.6	0.32	9.6	5.8
0.7	0.28	8.4	5.9
0.8	0.25	7.5	6.0
0.9	0.22	6.6	6.0
1.0	0.20	6.0	6.0
1.2	0.17	5.1	6.1
1.5	0.14	4.2	6.3

arithmetic mean value of 30 g/m^3 will not be exceeded the combination of design geometric means and standard deviation shown in Table 6 is necessary.

The m_{GM} values of Table 7 are reasonable and attainable in activated sludge processes. Although apparently quite small the standard deviations are also reasonable and attainable. The key factor is that 30 day σ values are related to single day value, by $1/\sqrt{30}$. A second problem results from the fact that a method of designing for a standard deviation does not exist. In practice it must be assumed that standard deviations attainable in other plants are possible in the one being designed.

Recommended Design Values

In conventional process design procedures average and peak loadings are incorporated into steady state models. In essence the 7 and 30 day averages used by regulating agencies is ignored and an attempt is made to design a system that will meet the requirements everyday. The general procedure of applying the log-normal distribution to design value selection was given above. Comparison of process by process configuration and setting a stability criteria of $\sigma_x = 10\ g/m^3$ resulted in the values given in Table 8. The recommended effluent SS values are difficult if not impossible to incorporate directly into a design. Obtaining these low values will require conservative overflow rates, however.

Operation

Application of statistical procedures to process operation provides a method of assessment and trend for a particular plant. Plants incorporating computer control can be provided with programs for the necessary calculations. Most plants do not have this capacity but the calculations are quite simple and once set up do not require more than a few minutes a week to update. Correlation with these results requires a years data and there is an advantage in having a complete seasonal cycle. If desired a longer period at a given plant would be useful, also. At a particular installation monthly values could be used and compared to the same periods on an annual basis.

When the time period has been chosen it would be advisable to determine the most appropriate statistical distribution to use. In most cases this will be the log-normal distribution but there is no reason to assume it to be the best in all cases. For the first period the log mean and log standard deviation values are calculated in the normal manner. The process of subtracting out the initial value and adding a new one is very straight forward and can be taught to operating staff without a background in statistics as a series of steps on a pocket calculator. One approximation must be made in determining the standard deviation because the mean value changes on a daily basis. It would be unusual for the mean to change enough in one or two days to effect the standard deviation significantly however. An alternative is to maintain a running years data on a cassette for a desk top minicomputer. The actual mean value could then be used in determining the standard deviation.

Knowledge of the statistical parameters associated with performance is useful in comparing a given plant to others and in assessing performance trends. For example it is useful to know if an apparently increasing mean value is within expected normal variation or if performance is actually decreasing. Detecting what plant

TABLE 7: GEOMETRIC MEAN AND STANDARD DEVIATION FOR 99th PERCENTILE AND 30 g/m^3 - 30 DAY ARITHMETIC AVERAGE

V_{GM}	M_{GM} g/m^3	σ_{GM} g/m^3
0.01	27.9	0.3
0.02	27.2	0.5
0.03	26.6	0.8
0.04	26.0	1.0
0.05	25.4	1.3
0.06	24.8	1.5
0.07	24.3	1.7
0.08	23.7	2.0
0.09	23.2	2.1
0.10	22.7	2.3

TABLE 8: RECOMMENDED DESIGN VALUES BY PROCESS CONFIGURATION (Niku et al, 1981b)

Process Type	Number of Plants	BOD $\leq$ g/m^3	SS $\leq$ g/m^3
Step feed/aeration	13	15	12
Conventional	18	15	12
Complete Mix	5	13	10
Contact Stabilization	4	13	11

component is failing is beyond the scope of the simple statistical methods used here, but in large plants more sophisticated analysis may be useful. An example would be estimating the effects of industrial spills.

As noted above weekly and seasonal cycles exist at many plants. Knowledge of these cycles can be used in operation. In many plants maintenance is scheduled for low flow seasons, already, but operational response could include temporary unit shut down over weekends, modifying aeration rates during periods of known low or high organic loading rates and changing process parameters in advance of influent characteristics changes.

Regulation Applications

Regulatory agencies typically evaluate performance on the basis of violations. While this is a reasonable method considerable knowledge is added if it is known that violations should be considered characteristic of a given plant because the average and standard deviations are high. Response to violations will undoubtably be different for plants having a high probability of repeatedly violating standards than for those with good reliability and stability.

Simple, standardized programs can be used with minicomputers in making statistical evaluations. In evaluating single plants manipulation of a years data is not time consuming and the information provided is far more useful than reports of particular violations.

REFERENCES

1. Niku, S., E.D. Schroeder and F.J. Samaniego (1979). "Performance of Activated Sludge Processes and Reliability Based Design" Journal of Water Pollution Control Federation, 51, 2841.

2. Niku, S. and E.D. Schroeder (1981a). "Stability of Activated Sludge Processes Based on Statistical Measures" Journal Water Pollution Control Federation, 53, 457.

3. Niku, S., F.J., Samaniego and E.D. Schroeder (1981b). "Discharge Standards Based on Geometric Mean" Journal Water Pollution Control Federation 53, 471.

4. Niku, S. and E.D. Schroeder (1981c) "Factors Affecting Effluent Variability From Activated Sludge Processes, Journal Water Pollution Control Federation, 53, 546.

5. Niku, S., R.S. Haugh and E.D. Schroeder (1981d). "Performance of Trickling Filter Plants" in press Journal Water Pollution Control Federation.

6. National Research Council (1946). "Sewage Treatment at Military Installations" Sewage Works Journal, 18, 789.

7. Schroeder, E.D. and G. T. Tchobanoglous (1975). "Another Look at The NRC Formula: Water and Sewage Works, 122, No. 7, 58.

8. Fair, G.M. and H.A. Thomas (1950). "The Concept of Interface and Loading in Submerged, Aerobic, Biological Sewage - Treatment Systems," *Journal and Proceedings, Institute of Sewage Purification*, pt. 3, 235.

9. Galler, W.S. and H.B. Gotaas (1964). "Analysis of Biological Filter Variables" *Journal Sanitary Engineering Division*, ASCE 90, SAG, 59.

10. Adams B.J. and R.S. Gemmel (1973). "Performance of Regionally Related Wastewater Treatment Plants," *Journal Water Pollution Control Federation*, 45, 2088.

11. Thoman R.V. (1970). "Variability of Waste Treatment Plant Performance" *Journal Sanitary Engineering Division*, ASCE, 96, 819.

12. Hann, R.W. et al. (1972). "Evaluation of Factors Affecting Discharge Quality Variation" Texas Water Quality Board, Environmental Engineering Division, Austin, TX.

13. Bertheoux P.M. (1974). "Some Historical Statistics Related to Future Standards *Journal Environmental Engineering Division*, ASCE, 100, 443.

14. Popel, H.J. (1976). "A Concept for Realistic Effluent Standards" *Progress in Water Technology*, 8, 1, 69.

15. Hovey, W.H., E.D. Schroeder and G. Tchobanoglous (1979). "Activated Sludge Effluent Quality Distribution" *Journal Environmental Engineering Division*, ASCE, 105, 819.

16. Townshend, A.R. (1968). "Statistical Analysis of the Effluent Quality of Biological Sewage Treatment Processes," *Proceedings*, *Third Canadian Symposium on Water Pollution Research*, Toronto, 272.

17. Lin, K.C. and G.W. Heinke (1977). "Variability of Temperature and Other Process Parameters, A Time Series Analysis of Activated Sludge Data" *Progress in Water Technology*, 9, 2, 347.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

PAPER NO. 10

EVALUATION AND DOCUMENTATION OF MECHANICAL RELIABILITY OF CONVENTIONAL WASTEWATER TREATMENT PLANT COMPONENTS

by

David W. Shultz
Senior Research Engineer

and

Van B. Parr
Staff Scientist

Southwest Research Institute
San Antonio, Texas 78284

EVALUATION AND DOCUMENTATION OF MECHANICAL RELIABILITY OF CONVENTIONAL WASTEWATER TREATMENT PLANT COMPONENTS

David W. Shultz, Senior Research Engineer
Van B. Parr, Staff Scientist
Southwest Research Institute

INTRODUCTION

There are approximately 21,000 publicly owned municipal treatment plants (POTWs) operating in the U.S. at the present time, with 1000-1200 new plants being constructed each year (1)(2). Since 1957, Federal grants exceeding $20 billion have been awarded to help state and local governments construct these treatment plants. Once constructed, local governments become responsible for plant operation in accordance with effluent discharge permit requirements established by the National Pollutant Discharge Elimination System (NPDES).

Many POTWs are apparently not meeting NPDES permit requirements. The General Accounting Office (GAO) concluded in 1970 that operation and maintenance problems with POTWs had been widespread for many years and had resulted in inefficient plant operations (3). A 1975 EPA analysis of 954 POTW inspections showed 386 plants had sufficient design and operational performance data to determine whether the plant was meeting design criteria for biochemical oxygen demand (BOD) removal. 40 percent of 305 plants were operating below design criteria for suspended solids removal. Other studies have indicated significant problems of non-compliance by POTWs with NPDES permits (4)(5)(6).

In recognition of these operational and maintenance problems, the U.S. EPA initiated a national research program dealing with performance and reliability of POTWs. A significant part of the effort involves determining the reliability of various mechanical components used at POTWs.

This study was conducted by Southwest Research Institute (SwRI) to quantify the in-service reliability of critical mechanical components found in four types of secondary wastewater treatment plants. The four types of plants included in this study were air activated sludge, oxygen activated sludge, trickling filter, and rotating biological contactor. The reliability statistics determined included mean time between failure (MTBF), mean time to repair (MTTR), and availability as a percent of scheduled operating time.

The technical approach, results, and conclusions are discussed in the following sections.

TECHNICAL APPROACH

Criticality Analysis

To determine the in-service reliability of critical mechanical components, the first step was to identify the critical components. The following components were identified as critical (i.e., failure would have an immediate impact on effluent quality); pumps, power transmissions, motors, compressors, diffusers, valves, controls, and conveyors.

A criticality analysis was then conducted to determine the component-application combinations to be included in the study.

A failure mode, effects, and criticality analysis was then performed for each of the four types of plants. In performing the analysis, it was assumed that there was no equipment duplication and that the plant was operating at the design condition. The resulting criticality rating for each component-application combination reflected the degree of impact on the effluent quality (significant, minimal, or no impact) as a function of time after failure (0-4 hours, 4-12 hours, or 24 hours).

From this analysis, the components selected for inclusion in the data collection effort were:

(1) Raw and intermediate wastewater pumps, power transmission and motors for all plant types,

(2) Return activated sludge pumps, power transmission and motors for air and oxygen activated sludge,

(3) Recirculation pump, power transmission and motors for trickling filter and rotating biological contactors,

(4) Motors and power transmission for final clarifiers for all plant types,

(5) Motors, power transmission, compressors, valves, controls and diffusers used in dissolved air production application and mechanical aerators in air activated sludge plants,

(6) Motors, power transmission, recirculation pumps, controls, diffusers and valves used in oxygen generation, application and recirculation in oxygen activated sludge plants,

(7) Liquid application systems for trickling filter plants,

(8) Compressors, motors, power transmission and controls used in primary clarifiers and primary sludge pumping in trickling filter and RBC plants,

(9) Recirculation pump controls used in secondary treatment in RBC plants,

(10) Raw and intermediate wastewater pump controls used in all plant types and valves used in raw and intermediate pumps in trickling filter plants,

(11) Controls used in dosing siphon in secondary treatment in trickling filter plants,

(12) Controls used in final clarifiers for all plant types, and

(13) Pumps, motors, power transmission and pressure vessels used in disinfection for all plant types.

Having defined the data collection requirements, the next step involved the selection of treatment plants having adequate records from which these data could be collected.

Data Source Selection

The data source selection process involved the following tasks: develop a list of candidate plants, select plants for one-day screening visits, conduct the one-day visits, and select study plants.

A candidate list of approximately 200 treatment plants was developed utilizing information from the U.S. EPA staff, equipment manufacturers and sales representatives, SwRI and subcontractor contacts, treatment plant operators and the literature. The criteria used to develop this list were primarily (1) that the plants satisfied the plant type requirements (i.e., air or oxygen activated sludge, RBC, or trickling filter); (2) there was an indication these plants would be willing to participate in the study; and (3) maintenance records were available.

Using information about these plants, forty-two plants were selected for direct contact by telephone. As a result, seventeen plants were identified for further consideration. One-day screening visits were then scheduled for each plant. The one-day visits were made to discuss the project with plant personnel and verify the suitability of plant records for the study.

Following the one-day visits, the treatment plants to be included in the data acquisition effort were selected. Criteria used to make the selection were as follows:

(1) Existence of adequate and complete preventative and corrective maintenance records for all major equipment components at each plant,

(2) Existence of plant equipment typical of the generic equipment found in the four types of treatment plants under consideration, and

(3) An indication that plant operations and maintenance personnel were willing to cooperate in the data collection effort.

Data Acquisition

A schedule was developed for visiting the various plants.

Upon arrival at each plant, the data collection team (engineer/operator and engineering technician) met with the plant staff involved. This meeting provided an opportunity for the data collection team to further explain the project and discuss possible uses of the project results.

At this point, data collection was started. Maintenance records for each critical component were reviewed. Data collection forms were used to code all data. An example is shown in Figure 1. Required data elements are shown at the top of this form. All data collected in the field were encoded using a numbering system which was developed to allow analysis of the data using a computer program. These codes are shown in the appropriate columns in Figure 1. For example, column one contains the code number 04-8731. The first two digits, 04, identify the plant location. The second four digit number represents a record number used to identify that specific piece of equipment. Column two, plant type, shows the number 05, which identifies this plant as a combination air/oxygen activated sludge plant. Codes for each of the remaining 23 columns are shown, with a description of what each code means shown below the code. Column 23 was for recording actual down time of sludge processing systems. Data for the sludge processing systems at each facility visited were recorded as shown at the bottom of Figure 1. These data allowed calculation of the mean time between failure and availability of the system.

The data collection from plant records often required a degree of judgment and interpretation. This was especially true when deciding when equipment had actually failed. A failure was defined as when the mechanical component no longer performed its intended function due to a failure of that component's subcomponent(s). In contrast, an equipment malfunction was defined as situations where the equipment could be placed back into service by minor cleaning and/or adjustments. Only data for down time considered to be caused by failure were recorded. Malfunctions including pump blockages, reduction in blower capacities due to dirty air filters, and plugging of air diffusers were not recorded. If interpretation of maintenance records was questionable, the data collection team conferred with plant maintenance staff to decide whether a failure had occurred.

Data Analysis

A computer program entitled "Wastewater Reliability Analysis Program--WRAP" was written to handle the sorting and analysis of the data base. Reliability, maintainability, maintenance and availability statistics were calculated from the data base across all plants for:

(1) Components,

(2) Components by application,

(3) Components by size,

(4) Components by generic group,

(5) Components by generic group by application, and

1 PLANT LOCATION	2 TYPE	3 UNIT OPERATION	4 BROAD CLASSIFICATION	5 GENERIC GROUPS	6 APPLICATION	7 SIZE	8 SUB-COMPONENT	9 CRITICALITY	10 DATE INSTALLED	11 % OPERATING TIME *	12 FAILURES	13 FAILURE MODE	14 CAUSE OF FAILURE	15 DOWN TIME	16 TIME TO REPAIR	17 ENVIRONMENTAL FACTOR	18 PART DISPOSITION	19 SUBCOMPONENT MFR	20 COMPONENT MFR	21 PART INV INFO	22 TYPE OF MAINT	23 DOWN TIME OF UNIT CP (SL Only)	24 COLLECTION DATE	25 CLOCK TIME TO REPAIR
WASTEWATER TREATMENT EQUIPMENT																								
04 - 8731	05	03	01	0114	03	04	023	01	0777	99	01	00	08	04	03	04	02	000	006	00	02		0879	0008
PLANT NO.4 UNIT NUMBER	COMBINATION AIR/OXYGEN ACT. SL.	SECONDARY TREATMENT	PUMPS	PUMP PROPELLER AXIAL	INTERMEDIATE WASTEWATER PUMP	100,000 GPM	BEARING, BALL DOUBLE ROW	EFFLUENT IMPACT WITHIN 4 HOURS	JULY, 1977	100 %	1 FAILURE	NOT KNOWN	NORMAL WEAR	24 - 168 HOURS	6 HRS. - 24 HRS	DRY BASEMENT	REPLACED	NOT KNOWN	ALLIS CHALMERS	NOT KNOWN	CORRECTIVE MAINTENANCE		AUGUST, 1979	8 HOURS
SLUDGE PROCESSING EQUIPMENT																								
04 - 4321	05	10							0776	99	11											1584	0879	
PLANT NO.4 UNIT NUMBER	COMBINATION AIR/OXYGEN ACT. SL.	INCINERATOR							JULY, 1976	100%	11 FAILURES											DOWN TIME 1584 HOURS	AUGUST, 1979	

FIGURE 1. SAMPLE OF A FIELD DATA COLLECTION FORM

(6) Components by generic group by size.

In addition, failure distribution information by subcomponent type for the first four categories listed above were also calculated. Also, reliability and availability statistics were calculated for sludge processes.

The statistics calculated from the data serve as the best summary of the data base in terms of the reliability, maintainability, maintenance, availability and subcomponent failure distribution parameters for the nine wastewater treatment plants. This information should be useful to other plant owners and operators, equipment manufacturers, and plant designers.

RESULTS

Component Performance Statistics

The performance statistics on critical components and sludge processes which were calculated from the data gathered at nine wastewater treatment plants are as follows:

Reliability Statistics--
- Overall mean time between failures (Overall MTBF)
- Maximum mean time between failures (Max MTBF)
- Minimum mean time between failures (Min MTBF)
- Lower limit 90% confidence level for the mean time between failure point estimate (overall 90% CL)

Maintainability and Maintenanct Statistics--
- Mean time to repair (MTTR)
- Preventative maintenance man hours per unit per year (PM-HRS/Unit/YR)
- Corrective maintenance man hours per unit per year (CM-HRS/Unit/YR)

Availability Statistics--
- Inherent availability (AVI)
- Operating availability (AVO)

Where $\text{AVI} = \dfrac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$; $\dfrac{\text{Total Hrs (TH)} - \text{TH Down Time (THD)}}{\text{Total Hrs (TH)}} = \text{AVO}$

These statistics have been grouped as follows:

(1) By component,
(2) By component by generic group,
(3) By component by application,
(4) By component by size/capacity,
(5) By component by generic group by application, and
(6) By component by generic group by size/capacity.

TABLE 1. RELIABILITY AND MAINTENANCE DATA FOR PUMPS--OPEN IMPELLER CENTRIFUGAL BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (x 10^6 Hrs)	Overall MTBF[1] (x 10^6 Hrs)	Min. MTBF (x 10^6 Hrs)	Max. MTBF (x 10^6 Hrs)	Overall 90% CL (x 10^6 Hrs)	PM-Hrs[2] Unit/ Year	CM-Hrs/[3] Unit/ Year	MTTR[4] (Hrs)	AVI[5]	AVO[6]
Raw Waste-water Pumping	34	60	.9277	.01530	-	-	.01303	.009442	.317900	8.483	.99400	.98450
Intermediate Wastewater Pumping	9	9	.1669	.01727	-	-	.01175	.107900	.787100	6.667	.99960	.95480
Return Activated Sludge Handling	27	28	1.0230	.03569	-	-	.02835	.001745	.102800	6.786	.99980	.99980
TOTAL	70	97	2.1176	.02166	.01530	.03569	.01911	.003428	.094773	7.825	.99962	.98955

[1] MTBF = Mean Time Between Failures
[2] PM = Preventive Maintenance
[3] CM = Corrective Maintenance
[4] MTTR = Mean Time to Repair
[5] AVI = Inherent Availability
[6] AVO = Operating Availability

An example of the type of reliability, maintainability, maintenance, and availability statistics which were calculated from the data is shown in Table 1, data for pumps by application.

Table 2 is an example of data on subcomponent failures by component type.

Table 3 is an example of the "by component" grouping showing reliability statistics for the eight components included in the data base, across all plants.

TABLE 2. PUMPS--OPEN IMPELLER CENTRIFUGAL

Rank	Subcomponent Type	No. of Failures	Relative Frequency
1	Impeller Wear Ring or Plate	15	.197
2	Seal, Packed, Water, Oil, Grease Lubricated	14	.184
3	Solenoid Valve	14	.184
4	Bearing, Ball, Double Row	6	.079
5	Bearing, Cast, Pillow	5	.066

TABLE 3. MEAN TIME BETWEEN FAILURE (MTBF) FOR COMPONENTS

Component	Overall MTBF (x 10^6 Hrs)	Min. MTBF (x 10^6 Hrs)	Max. MTBF (x 10^6 Hrs)	Overall 90% CL (x 10^6 Hrs)
Pumps	.032066	.021662	.074191	.028630
Power Transmissions	.035620	.017850	.710910	.033170
Motors	.066700	.010880	.114820	.061220
Compressors	.007140	.005620	.083920	.006310
Diffusers, air/water	.018130	.012630	1.834000	.016670
Valves	.014440	.008930	.032590	.010400
Controls	.083580	.003930	.100640	.075690
Conveyor (unconfined materials handling)	.148480	.061750	.358560	.116900

Table 4 presents the maintainability, maintenance, and availability statistics for eight components across all plants.

TABLE 4. MAINTENANCE STATISTICS FOR COMPONENTS

Components	PM-Hrs/ Unit/Yr	CM-Hrs/ Unit/Yr	MTTR (Hrs)	AVI	AVO
Pumps	.00227	.05177	9.541	.99968	.99116
Power Transmissions	.00032	.00469	2.273	.99994	.99898
Motors	.00098	.00660	6.854	.99989	.99816
Compressors	.03399	.17843	0.960	.99987	.99306
Diffusers, air/water	.00065	.04664	8.305	.99951	.99875
Valves	.00684	.73845	11.615	.99879	.96446
Controls	.00025	.00261	3.696	.99996	.99870
Conveyor (unconfined materials handling)	.00055	.10086	4.768	.99996	.99980

Sludge Process Performance Statistics

As previously indicated, failure data for sludge processes were collected at the nine treatment plants. Table 5 presents the results of the data analysis for five processes.

TABLE 5. WWTP REPORT-RELIABILITY OF SLUDGE PROCESSES

Process	Operating Hours ($x 10^6$ Hrs)	No. of Failures	MTBF ($x 10^6$ Hrs)	90% CL ($x 10^6$ Hrs)	AVO
Sludge Process External to WW Treat. Process	.780	400	.195	.183	.997
Anaerobic Digestion	.678	40	.167	.137	.100
Incineration	.374	454	.824	.776	.723
Sludge Thickening DAF	.406	702	.577	.550	.994
Vacuum Filter	.697	1150	.606	.583	.931

CONCLUSIONS

Based upon the results of the performance data collection and analysis effort conducted during this project, the following general conclusions are made:

(1) Three types of performance statistics (reliability, maintainability, and availability) have been determined for selected critical mechanical components of wastewater treatment plants.

(2) These statistics were not available elsewhere in the literature, from manufacturers or owners of equipment.

(3) These performance statistics can be used by design engineers as a tool to (a) compare and predict performance of generic equipment in various applications, and (b) design reliability into new treatment plants.

(4) These data can be used by operators of wastewater treatment plants to develop spare parts inventories for new equipment and establish preventative maintenance programs.

(5) In spite of the significant number of operating hours included in this study, this data base does not cover all the size ranges or types of equipment found in the 20,000 treatment plants operating in the U.S. Lacking are data for many small size range components. It was found that these records are not routinely kept by the smaller plants surveyed during this study.

(6) The quality of data obtained from the nine treatment plants was good. The form of record keeping sometimes required judgments as to appropriateness with respect to project data requirements.

(7) Effluent quality from wastewater treatment plants can be expected to improve (to the extent that equipment failure causes decreases in quality) over the long term by use of performance statistics by design engineers and operators. Training will be required to help these people know how to utilize such data. For example, design engineers can utilize these data as an additional tool to be used for the selection of equipment, determination of the reliability and availability of unit operations as well as entire treatment systems, and the prediction of operational performance of equipment in various applications. Plant owners/operators can utilize preventative and corrective maintenance data to help refine overall future maintenance budget and staffing projections. Knowledge of equipment failure rates and subcomponent failures can provide input into determining spare parts inventories.

REFERENCES

1. Smith, J. M., F. L. Evans, and J. H. Bender. Improved Operation and Maintenance Opportunities at Municipal Treatment Facilities. Wastewater Research Division, MERL, EPA, Cincinnati, Ohio, 1980. 45 pp.

2. U.S. EPA, Clean Water Report to Congress, Washington, D.C., 1975-1976.

3. Comptroller General of the United States. Continuing Need for Operation and Maintenance of Municipal Waste Treatment Plants. Report to Congress, Washington, D.C., CED-77-46, April 1977.

4. Hegg, G.A., K.L. Rakness, and J.R. Schultz. Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance. EPA 600/2-79-034, NTIS No. PB-300331/AS, June 1979.

5. Gray, A.C., P.E. Paul, and H.D. Roberts. Evaluation of Operation and Maintenance Factors Limiting Biological Wastewater Treatment Plant Performance. EPA 600/2-79-078, NTIS No. PB-80-108947, July 1979.

6. Weston, R.F., Inc. Manual for Identification and Correction of Typical Design Deficiencies at Municipal Wastewater Treatment Facilities. Draft Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1981.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

PAPER NO. 11

FAIL SAFE DESIGN CONCEPTS

by

Roy O. Ball, Ph.D., P.E.
Principal

ERM - North Central, Inc.
200 South Prospect Avenue
Park Ridge, Illinois 60068

FAIL SAFE DESIGN CONCEPTS

Roy O. Ball, Ph.D., P.E.
Principal
ERM-North Central, Inc.

The objective of this investigation on "fail safe" was to evaluate the potential application of fail safe concepts to the design and/or operation of POTW's.[1] If application of the concept appears promising, then EPA would consider an expanded R&D investigation of fail safe POTW design and operation.

The first question we had to answer in this investigation is,"what is fail safe?" It is easier to say what fail safe is not then what it is. The objective of investigating fail safe operations is to improve POTW reliability without reliance on sophisticated operation, mechanical redundancy, or elaborate instrumentation. As you can see, the term fail safe is different from that used in other fields. Based on the exclusionary criteria above, there appear to be three major concepts that can be considered fail safe: mechanical interlock, mechanical simplicity, and latent energy.

Mechanical interlock are those processes in which performing action A insures that action B is also performed, generally through direct mechanical linkage. An example (unrelated to POTW operation) is providing that the only key that can lock a car is the ignition key. In POTW's, a simple example is a center pivoted chute to divide waste sludge flow to one of two tanks. If the chute is pivoted to one tank, it necessarily excludes the other.

The second concept is mechanical simplicity, the ultimate of which is no moving parts. Other speakers of this conference are addressing the subject of mechanical reliability; that is, extending the mean time between failures, failure being defined as an operation that reduces the effluent quality from the facility. Mechanical simplicity, for the purposes of fail safe, is defined as being fewer failure modes of equal probability; that is to say if the facilities in any two plants are compared one to one, and one plant contains fewer items having equally probable failure modes, then one plant is said to be more mechanically simple compared to the other. A common example would be a plant in which there is an influent lift station and also a lift station between primary and secondary treatment. Elimination of one of the lift stations provides a more mechanically simple plant.

The third concept is that of latent energy. Four separate categories of latent forces have been identified.

The first is gravity, which would include hydraulic head and density related phenomena.

The second latent energy source is electromagnetic radiation which would include incident solar radiation. Wherever there is a naturally generated source of electromagnetic radiation, then there is an opportunity to capture that radiation as a free energy source or, more realistically, a reliable energy source.

The third type can be generally referred to as the teleonomic behavior of bacteria and plants. By teleonomic, we mean that for reasons of their own, bacteria and plants exist and grow wherever it is possible to do so. By virtue of their existence and growth, they necessarily create gradients, and thereby the opportunity for transport of materials and their subsequent oxidation or alteration. Although we may provide conditions where such bacteria or plants can flourish, we in fact are not tampering with their intent or desire to grow, reproduce, and multiply.

The fourth type of latent energy includes molecular forces which would include such things as forces described by Hamaker constants and viscosity.

Why are these fail safe operations attractive? In general, they replace operation skills with maintenance skills and in many conditions, it is more practical to provide consistent, reliable maintenance than it is consistent, reliable operation.

The next step in this evaluation was to provide a list of examples of fail safe operations that achieve certain objectives. For example, if the objective is liquid/solid separation, such devices as gravity sedimentation, swirl concentrators (which trade inertia for separation energy), and hydrosieves are processes which seem to embody one or more fail safe principals. A fourth example is the enhancement of coagulation and flocculation by ion addition.

Examples of fail safe operations which accomplish flow regulation are side leaping weirs (frequently used in stormwater management), proportional weirs (often used to control velocities in grit chambers), siphons, and other hydraulic structures.

In addition to defining fail safe devices, it was necessary to determine the objectives of main stream treatment. Approximately 35 objectives within five major categories; flow control, pretreatment, primary treatment, secondary treatment, and post-treatment were defined. As an example, secondary treatment frequently consists of two parts: a bioreactor and a clarifier. The objectives of the clarifier are fivefold:

1. to remove particulate BOD;
2. to return biosolids to the reactor (with the objective of reducing its size);
3. concentrate waste activated sludge;
4. store the concentrated waste activated sludge; and
5. remove suspended solids from the effluent stream.

Therefore, when we consider the application of fail safe operations, we do not need to replace all five objectives (conventionally achieved with some degree of success) of a secondary clarifier with a single device. We can, rather, improve or satisfy some of the objectives by fail safe means. For example, two of the fail safe devices which were discussed in this evaluation were in-channel clarification and porous wall reactors. For in-channel aeration, the objective of returning biosolids to the reactor is now achieved in a fail safe way, as the solids are never removed in the first place. In the porous wall reactors, several of the objectives are achieved. The biosolids return is achieved because, again, they are never removed from the reactor. In addition, because very high mixed liquors can be maintained, the removal of particulate BOD and the concentration and storage of waste activated sludge are also accomplished using fail safe concepts. Due to the build-up of microbial growth in the pores of the walls, the removal of TSS from the effluent stream is also achieved with very high efficiency. In fact, the reactors must be cycled to allow digestion of this film or the head difference between the inside of the reactor and the exterior will become too great.

In this investigation, therefore, we ended up with a matrix which compared treatment objectives such as those described above, with fail safe operations. In each block of the matrix, the type of fail safe concept was identified; that is, mechanical interlock, mechanical simplicity, or latent energy. It was also indicated whether or not that operation was fully applicable to that objective, inapplicable to that objective, or partially applicable. Where it was partially applicable, it could be either based on climate, topography (for example, available hydraulic head) or other factors. It was also indicated whether or not the fail safe operation could be applied on both a new and a retrofitted basis or only new or only retrofitted.

In summary, the major benefit of fail safe operations is that they require maintenance and not operation. The major problem with fail safe operations is that they require maintenance and not operation. Once the fail safe devices are installed, there is little active control, in many cases, that can be exerted. For these reasons, a fail safe installation generally needs steady flow and good administration.

Where can fail safe be applied? Small plants without fulltime operators would appear to be a natural application. Also, remote sites where several plants are supervised by one person would seem to be candidates. The Department of Defense installations, which frequently have excellent maintenance but transient operation, would appear to be another place where these concepts can be applied. Because of the problems of steady flows, it is possible that some of these concepts are applicable at very large facilities as well.

In summary, as stated before, the objective of this study was to determine the potential for application of fail safe principals to POTW's. Based on the review described above, we believe that the potential is significant.

---

[1] Presentation based on a study by Roy F. Weston, Inc. for EPA MERL.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

SESSION NO. 4
Improving POTW Design

PAPER NO. 12

DESIGN DEFICIENCIES IN POTWs

by

Roy O. Ball, Ph.D., P.E.
Principal

ERM - North Central, Inc.
200 South Prospect Avenue
Park Ridge, Illinois 60068

DESIGN DEFICIENCIES IN POTWs[1]

Roy O. Ball, Ph.D., P.E.
Principal
ERM-North Central, Inc.

So far in this symposium, you have heard a number of presentations describing EPA funded reports, all of which have the objective of describing factors which can prevent POTWs from proper operation and attaining their design effluent quality. Bob Hegg has discussed his survey of facilities and identification of any such factors. Kimm Perlin described factors involved in the operation and maintenance of land treatment facilities which can impact performance. Bob Crosby has described his measurements of the flow and secondary clarifiers. I presented a description of the report on side streams which can, in some cases, have very serious effects on plant performance. Professor Boyle has described biofouling of aerators. Dave Schultz has discussed the mechanical reliability of facilities and how to prevent treatment plant failures due to mechanical problems. Ed Schroeder has provided statistical information on the overall performance and reliability of plants. With regard to new concepts for facilities or rather the reapplications of old concepts, this morning I described the fail safe feasibility investigation and Jon Bender discussed, as part of the design information series, the effect of hydraulic variation on treatment performance.

The design deficiencies report I wish to now describe is a catalog of factors or actions that either did or did not occur during the design process that could impact the performance or operability of the POTW. The report is in 14 major sections by process area. For each section, the deficiencies are grouped as being either general, hydraulic, structural, electrical, mechanical, or instrument related. The deficiencies each carry a number, and on the matrices at the front of the report, it is possible to rapidly locate any particular deficiency by using the matrix numbers as indicated in this example. Alternatively, the operator designer can turn to the section on a particular process and rapidly leaf through all of the identified deficiencies of the mechanical type to insure that his design has included and dealt with any such potential problems.

I will now describe the organization and format of the design deficiencies report in more detail. The report was designed to facilitate the location of information concerning typical design deficiencies found in various wastewater treatment systems and, more specifically, individual unit operations, and to reference the deficiencies noted with related solutions. The report is divided into two main sections:

- Design Deficiencies Matrix

- Design Consideration and Correction Modules for POTWs.

Design deficiencies commonly found in the POTWs are categorized in a matrix format. The 15 categories utilized are listed below:

Number	Category
1.0	General Plant Design
2.0	Preliminary Treatment
3.0	Primary Treatment
4.0	Air Activated Sludge
5.0	Oxygen Activated Sludge
6.0	Trickling Filter
7.0	Disinfection
8.0	Anaerobic Digestion
9.0	Aerobic Digestion
10.0	Sludge Dewatering
11.0	Lagoons
12.0	Land Application
13.0	Sludge Disposal
14.0	Sludge Reduction
15.0	Rotating Biological Contactors

The deficiencies within each category are further grouped according to type and then numerically referenced to unit operations and components specific to the category. The deficiency groups used include:

- Layout, Arrangement, and Placement of Components in Design of Plant.

- Hydraulic Design Considerations.

- Mechanical Design Considerations.

- Electrical/Instrumentation Design Considerations.

- Safety Considerations.

- Environmental Considerations.

The design deficiencies listed in the matrix are discussed in "Design Consideration Modules" in terms of items that should be reviewed by the engineer furing design of a new or expansion of an existing wastewater treatment plant. Features of the module format are as follows:

- The report section, design consideration category, and applicable unit operation or component are indicated in the upper left-hand corner.

- A treatment plant block flow diagram is presented in the upper right-hand corner. The deficiency category represented by the module is shaded to allow the reader to visually identify the portion of the plant discussed.
- The design deficiencies, including reference number and description, are presented in a column on the left side of the page and the associated design consideration discussed in a column opposite the deficiency.
- The reference numbers for the deficiencies discussed in each module are summarized at the bottom of the page. This facilitates locating specific deficiencies when referring to the modules.
- The modules are sequentially numbered for cross-referencing with the module table of contents.

Suggested methods to correct the design deficiencies, when already present at an existing wastewater treatment facility, are presented in the document. The correction procedure, where applicable, includes the following items:

- Method.
- Materials.
- Cost.
- Sketch.

The format of the document allows the reader the flexibility to obtain information either through the deficiency matrix or the design consideration/correction modules. A POTW operator experiencing a specific problem at his plant should first refer to the deficiency matrix in order to identify the appropriate module(s) that describes methods that can be used to correct the problem. On the other hand, an engineer may wish to proceed directly to the design consideration modules in order to identify those items he should review during design of a specific unit operation or component.

The correct procedure for using the design deficiency matrix is as follows (see Figure 1 for illustration):

1. Select the appropriate matrix category (i.e., preliminary, primary, activated sludge, etc.) and refer to that section of the matrix.
2. Determine which deficiency group (i.e., mechanical, hydraulic, safety, etc.) the problem falls under and turn to that portion of the matrix.

3. Identify the applicable unit operation or component and move down that column until the desired deficiency is located. (NOTE: If the deficiency is not listed, refer to the deficiency list and determine if it is listed under another unit operation.)

4. Use the three digit deficiency reference number to identify the related deficiency/correction module as follows:

   1st Digit -- Category Number

   2nd Digit -- Unit Operation/Component number (i.e., column number)

   3rd Digit -- Deficiency Number

5. Turn to the deficiency/correction module that has has the same category and unit operation/component number.

6. Read down the left-hand column to the applicable deficiency reference number.

7. The suggested correction method is described in the opposite right-hand column.

8. Related considerations aimed toward preventing the deficiencies during design are also discussed in the opposite right-hand column.

In many examples, the deficiency correction at existing POTWs was a reiteration of the design consideration. To avoid repetition, only the design consideration is presented.

All the deficiencies described in this report seem to persist in the design field. Perhaps the reason is that the person who performs the conceptual design of the plant, although he may have in mind many of these difficulties, does not fully communicate his concerns to the people preparing the plans and specifications. Frequently, too, the plans and specifications are not reviewed by someone knowledgeable and experienced in the operation and maintenance of treatment plant facilities. Also, if there are such deficiencies, many times they are of a positional nature and may not be readily corrected without redoing much of the final design. Whatever the reason, it appears that few, if any, firms have attempted to make such a comprehensive catalog of problems that can occur. The intent of this catalog is not to substitute our judgment or discretion for the designers, but rather to provide an indication of problems that have arisen at other treatment facilities and have been considered serious enough to impact the performance or operability of the facility.

At this point, I would like to ask members of the audience to provide us with examples of design deficiencies that they have noted. For my part, I will point out whether or not these are included in the catalog or what other allied deficiencies are also included, if any.

Based on the degree of participation here, it is evident that this subject is of some general interest to members of our profession. It is EPA's hope, and mine, that this document will serve as a valuable starting point for the continued cataloging of such deficiencies, with the ultimate objective of improving the operability and reliability of POTW's.

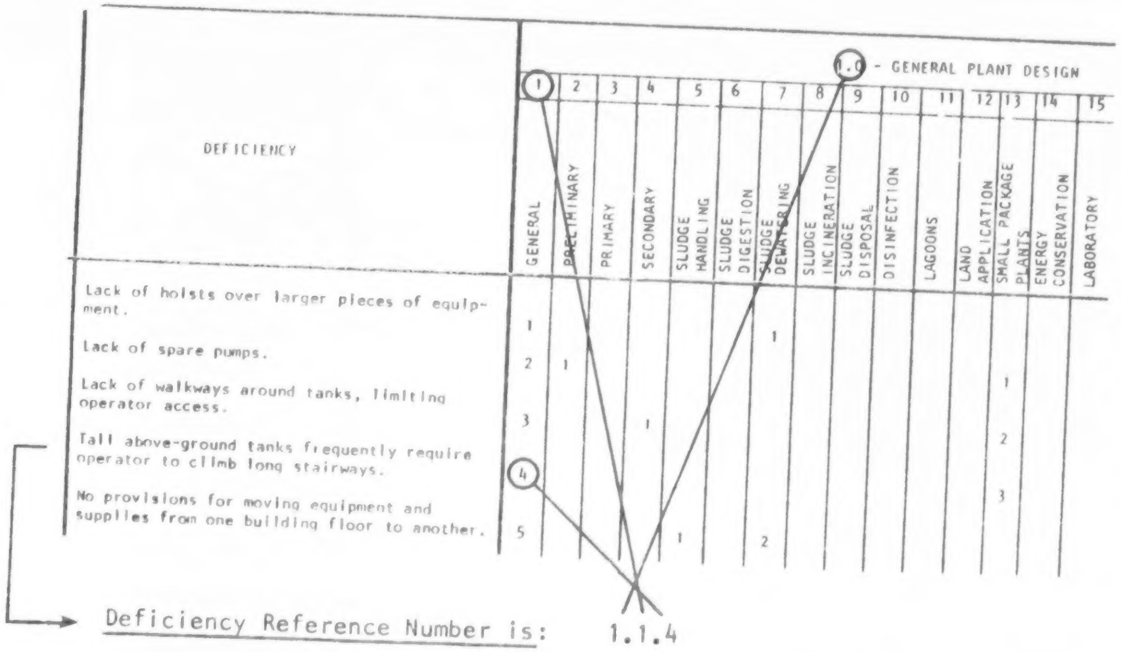

1.0 - GENERAL PLANT DESIGN
DEFICIENCY
1 GENERAL
2 PRELIMINARY
3 PRIMARY
4 SECONDARY
5 SLUDGE HANDLING
6 SLUDGE DIGESTION
7 SLUDGE DEWATERING
8 SLUDGE INCINERATION
9 SLUDGE DISPOSAL
10 DISINFECTION
11 LAGOONS
12 LAND APPLICATION
13 SMALL PACKAGE PLANTS
14 ENERGY CONSERVATION
15 LABORATORY
Lack of hoists over larger pieces of equipment.
Lack of spare pumps.
Lack of walkways around tanks, limiting operator access.
Tall above-ground tanks frequently require operator to climb long stairways.
No provisions for moving equipment and supplies from one building floor to another.
1
2
3
4
5
1
1
1
1
2
3
1
2
Deficiency Reference Number is: 1.1.4

FIGURE 1

---

[1] Presentation based on an investigation and report by Roy F. Weston, Inc. for EPA MERL

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

PAPER NO. 13

PERFORMANCE CAPABILITIES AND DESIGN OF OXIDATION DITCH PROCESSES

by

William F. Ettlich
Vice President

Culp/Wesner/Culp
El Dorado Hill, California 95630

PERFORMANCE CAPABILITIES AND DESIGN OF OXIDATION DITCH PROCESSES

William F. Ettlich, Vice President
Culp/Wesner/Culp

DESIGN FEATURES OF OXIDATION DITCH PLANTS

An oxidation ditch plant is typically an extended aeration type of activated sludge process that uses a continuously recirculating closed loop channel or channels as an aeration basin. The aeration basin is normally sized for a 24-hour hydraulic retention time, but may be designed for any other detention time. Mechanical aerators are commonly used for mixing, oxygen supply, and for circulation of mixed liquor. Generally, these are horizontal brush, cage, or disc-type aerators designed specifically for oxidation ditch plants. Secondary clarifiers similar to those used in other activated sludge processes are normally provided. Primary clarification is not usually included in oxidation ditch plant design.

The typical oxidation ditch aeration basin is a single channel or multiple interconnected concentric channels. An oxidation ditch plant normally consists of one or more basins of either type operated in parallel depending on the flow and operation mode required. Channel geometry can vary to include many possible configurations, however, the single oval configuration is the most common. The multiple concentric channel basin can have any number of interconnected channels with three to five being typical and provides some process flexibility since it can be changed to other activated sludge modes with minor modification. Typically, the outer channel is used for aerobic digestion of the waste activated sludge. Shallow channels are typically four to six feet deep with 45 degree sloping side walls. Deep channels have vertical side walls and are normally 10-12 feet deep. The channels are usually lined to prevent erosion and leakage. Ditch lining can be reinforced concrete, gunite, asphalt, or thin membranes. Typically, shallow channels with sloped side walls are constructed of concrete poured against earth backing with welded wire mesh reinforcing. Deep vertical wall channels require reinforced concrete walls.

Several manufacturers supply oxidation ditch brush or disc type mechanical aerators. These units may be either fixed or floating. The aerators normally span the channel width and may be installed in one or more locations around the channel. The aerators must supply the required oxygen to the channel and impart a sufficient velocity in the channel (>1.0 FPS) to keep the channel contents in suspension. Oxygen transfer capabilities of an aerator will vary depending on the particular design, rotational speed and submergence. Most units operate in the range of 60 RPM to 110 RPM with a submergence of 2 to 12 inches and produce oxygen transfer rates of from 3 to 5 lbs of oxygen per hour. The number of aerators provided depends on the size, configuration and oxygen requirements of the plant. A minimum of two aerators should be installed so that at least partial aeration can be maintained with one unit out of service.

There are many available configurations of plants and aerators and it is recommended that care be taken to select the most energy efficient configuration because aerator energy is a major operating expense for oxidation ditch plants. There should be little actual difference between manufacturers aerator power requirements for given size plants.

The real problems (and differences) in rotor configurations are mechanical; the drive unit, line bearings, seals, aerator torque tube, materials of construction and similar considerations. These are the features that will have the greatest impact on long term operation and maintenance of the plant.

The mechanical features should receive careful consideration in design and preparation of specifications. Most of the bearings associated with aerators are of the ball or roller type; grease lubricated with seals. Therefore, bearings and drive units should be protected from splashing water both to keep the water off and to provide convenient access for maintenance personnel. Extension of bearing grease fittings up to convenient locations on catwalks or easily accessible locations will certainly contribute to more satisfactory maintenance. Means for field alignment of bearings should be provided and bearings should be carefully aligned prior to operation. The bearing supports for horizontal aerators may be up to 30 feet apart and differential settling with eventual loss of alignment may occur if this is not considered in the structural design of the aerator support foundation. Generally, bearings with some self alignment capability will provide more satisfactory long term service, but this feature does not reduce the need for proper structural design and initial alignment.

Some means must be provided for removal of the aerator; either a permanently installed lifting mechanism, a portable lifting mechanism, or access for mobile lifting equipment.

Many problems were caused by the aerator "slinging" mixed liquor onto adjacent structures and onto aerator bearings, couplings, seals, and drive units. Most aerators have "slingers" at each end, but they only compound the problem when the wind is blowing as liquid flying off the "slinger" is blown by the wind. Mixed liquor which lands on adjacent walkways causes ice formation when it is cold and algal growths cause slippery conditions at other times. Bearings and drive units should be adequately shielded from the inevitable liquid spray.

The long narrow aeration channel of the oxidation ditch plant provides a complete mix activated sludge process. Even though a plug flow mode would seem to be applicable, the minimum velocity of 1.0 fps results in a cycle time of less than 15 minutes in the longest channels used. Compared to the typical 8 to 24 hour detention time design, the channel circuit time becomes insignificant. Therefore, the oxidation ditch may be considered a completely mixed activated sludge process (CMAS) with respect to organic load. It is not completely mixed with respect to dissolved oxygen profile because this profile can vary significantly around the channel and vertically within the channel. The mixed liquor can pass through varying oxygen rich or deficient zones as it passes around the channel.

The procedure for design of an oxidation ditch plant is basically the same as used for an extended aeration process with emphasis given to the hydraulic considerations imposed by the basin geometry. The manufacturers can provide assistance in design for specific applications.

Some low alkalinity wastewaters may require pH adjustment when subjected to extended aeration because of nitrification.

Oxidation ditch plants are designed for long sludge retention times and nitrification will occur if sufficient oxygen is provided. Usually, sufficient oxygen should be provided for complete nitrification in addition to satisfying the carbonaceous BOD requirements. Complete mix activated sludge plant design procedures have been described by McKinney(1), Eckenfelder(2), and Monod(3), and presented in a unified model by Goodman(4,5). It is frivolous and time consuming to compare the nuances of these various models; proper use of any of these models results in sufficiently accurate results for design purposes.

Screening seems to be the single most important pretreatment step. If rags, boards, and other similar objects are not removed prior to the ditch they will cause trouble with the aerators and will, in most cases, plug sludge control valves (telescoping valves), sludge lines, sludge pumps, and weirs. Few problems have been observed or reported directly related to inadequate grit removal although it is certain that this grit accumulates in the ditch and will have to be removed at some time.

Generally, final clarifier design is consistent with other activated sludge processes. A surface overflow rate of 400 to 500 gpd/sq ft is recommended for average daily flows and 1,000 to 1,200 gpd/sq ft at peak flows. Many plants are constructed with 8 foot deep clarifiers, but depths of 10 to 14 feet provide greater process reliability.

Any biological plant design must consider the quantity of sludge produced, the nature and stability of the sludge, and suitable disposal procedures. An oxidation ditch plant, operated in the extended aeration mode, has certain inherent advantages relative to sludge handling and disposal. Oxidation ditch plants can be operated at a 20 to 30 day SRT resulting in a sludge having characteristics similar to a well stabilized aerobically digested sludge. A conventional activated sludge plant operated at a 4 to 10 day SRT will produce a sludge with high residual biodegradable organic content. If placed on drying beds or on the land, it will become odorous and objectionable. Aerobic digestion of this sludge for 7 to 15 days is normally required to produce a stable product suitable for disposal on drying beds or the land. For a properly operated conventional activated sludge plant plus aerobic digestion the total SRT prior to disposal will be 15 to 20 days. In effect, the oxidation ditch extended aeration process provides sludge stabilization equivalent to conventional activated sludge plus aerobic digestion.

In most oxidation ditch plants where the extended aeration process is used (16 to 24 hours aeration detention) sludge is wasted directly to open drying beds. In a few cases sludge is wasted directly to tank trucks which spread the liquid sludge on the plant grounds or on adjacent land. Field inspections of oxidation ditch plants revealed no odor problems at plants using either method. The field inspections consistently confirmed the lack of odor problems with sludge from the extended aeration oxidation ditch plants. Several plants complained of insufficient drying bed capacity because of poor dewaterability especially during periods of cold or wet weather. Adequate drying bed capacity must be considered carefully in design.

Some design engineers and regulatory authorities may require additional sludge stabilization for oxidation ditch plants operated in the extended aeration mode. Part of the consideration may be the possibility of periodic poor operation of the process. Also, future flow increases may force operation of the plant at shorter SRT's to the point where additional sludge stabilization is required.

The quantity of sludge produced is related to the characteristics of the incoming wastewater solids. Normally, wastewater solids contain fractions that are inert, volatile and nonbiodegradable, and volatile and biodegradable. The inert (nonvolatile) and volatile/nonbiodegradable fractions will accumulate in the system solids inventory in proportion to the SRT. Normally 20 to 25 percent of the raw waste suspended solids are inert. The remaining 75 to 80 percent are volatile solids with, typically, 30 to 40 percent nonbiodegradable. Therefore, about half of the incoming suspended solids are not subject to biological action and will accumulate in the mixed liquor in proportion to the SRT. Proper sludge wasting is absolutely necessary in extended aeration plants as with conventional activated sludge plants or the excess solids will be automatically wasted periodically in the secondary clarifier effluent.

COMPARATIVE PERFORMANCE & RELIABILITY

Performance and reliability data for oxidation ditch plants were developed from actual plant operating records, obtained from published literature, telephone and letter contact with operating plants, visits to operating plants, EPA records, special studies, and engineer's files. There were very few plants where complete data could be obtained for all desired parameters. In addition, reliance had to be placed on the sampling and analysis methods used by various plant personnel. It is recognized that these procedures are not consistent from plant to plant and therefore, not always directly comparable. Nevertheless, the results represent the data as obtained without modification. Inordinately high or low readings were not removed from the data during compilation because most plants experience these variations at one time or another. It is felt that these variations do occur in oxidation ditch plants as in most other activated sludge plants.

Oxidation ditch plant performance was developed primarily from monthly average data. Generally, the data from a plant were not used unless several data points were available. Plant daily performance data, when available, were converted to monthly averages, which were then analyzed for each plant.

Where possible, the performance is calculated for both summer and winter. Winter is arbitrarily determined to be the months of November through March. The "average" performance was determined by averaging the performance of all of the individual plants. The high and low individual plant performance is shown to establish the range limits of individual plants.

Based on an analysis of available data it was found that both BOD_5 and suspended solids removal appear to be relatively independent of plant capacity.

Performance data from 29 oxidation ditch plants from various United States and Canadian locations are summarized as follows:

SUMMARY PERFORMANCE OF 29 OXIDATION DITCH PLANTS

	Effluent, mg/L			Removal		
	Winter	Summer	Average annual	Winter	Summer	Average annual
BOD_5						
High plant	55	34	41	87	86	87
Average	15.2	11.2	12.3	92	94	93
Low plant	1.9	1.0	1.5	99	99	99
Suspended solids						
High plant	26.6	19.4	22.4	81	82	82
Average	13.6	9.3	10.5	93	94	94
Low plant	3.1	1.9	2.4	98	98	98

The performance of competing biological treatment processes was also evaluated and the data are summarized as follows:

PERFORMANCE - COMPETING BIOLOGICAL PROCESSES

	Effluent, mg/L		Removal, %	
	TSS	BOD_5	TSS	BOD_5
Activated sludge (1.0 mgd)	31	26	81	84
Activated sludge (Package Plants)	28	18	–	–
Trickling filters	26	42	82	79
Rotating biological contactor	23	25	79	78

Analysis of data from 12 operating oxidation ditch plants showed the reliability for meeting various BOD_5 and TSS effluent standards as follows:

RELIABILITY - OXIDATION DITCH PLANTS

	% of time effluent concentration (mg/L) less than					
	10 mg/L		20 mg/L		30 mg/L	
	TSS	BOD_5	TSS	BOD_5	TSS	BOD_5
Best plant	99	99	99	99	99	99
Average all plants	65	65	85	90	94	96
Worst plant	25	20	55	55	80	72

Of the plants analyzed, the effluent BOD_5 and TSS seldom exceeded a maximum of 60 mg/L.

The reliability of competing biological treatment processes was evaluated on the same basis and is summarized as follows:

AVERAGE RELIABILITY - COMPETING BIOLOGICAL PROCESSES

	% of time effluent concentration (mg/L) less than					
	10 mg/L		20 mg/L		30 mg/L	
	TSS	BOD_5	TSS	BOD_5	TSS	BOD_5
Activated sludge (1.0 mgd)	40	25	75	70	90	85
Activated sludge (Package Plants)	15	39	35	65	50	80
Trickling filters	-	2	-	3	-	15
Rotating biological contactor	22	30	45	60	70	90

An oxidation ditch plant is capable of 95% to 99% nitrification without design modifications. This high degree of nitrification even at wastewater temperatures approaching 0°C is possible due to the 24-hour hydraulic retention time in the channel(s) and the capability of operating at a high solids retention time (SRT) of 10 to greater than 50 days.

Nitrogen removal by single-stage biological nitrification-denitrification has also been achieved at properly designed and well operated oxidation ditch plants. Nitrogen removal is achieved by producing both aerobic and anoxic zones within the same channel. These zones are created by controlling the aerator oxygen transfer rate so that mixed liquor dissolved oxygen is depleted within a portion of the aeration channel.

The carbon source for the anoxic zone (denitrification) is provided by feeding the raw sewage into the channel upstream of the anoxic zone. With careful operation, 80% nitrogen removal has been achieved in a single channel oxidation ditch plant.

OXIDATION DITCH PLANT OPERATION

As a group, oxidation ditch plants appear to perform consistently well in spite of limited operation and maintenance in a number of cases. All plants visited appeared to have adequate aeration capacity, adequate velocity in the ditch, an acceptable mixed liquor and a lack of odor or other nuisance. In general, the operators were able to obtain good treatment results in almost all cases. Sludge handling and disposal was relatively simple and trouble free, however, in some cases operators reported difficulties in dewatering the sludges on open drying beds due to lack of proper bed area or due to slow dewatering of the sludge. The plants were easy to keep in service and would operate for long periods of time with very little operation and maintenance. Many plants operated for periods of time unattended (evenings and weekends) without significant problems. No particular type of oxidation ditch plant seemed to stand out as superior or substandard; the relative performance depended on many more factors such as original design criteria (clarifier surface overflow rate for instance) and operational procedures. There are some exceptions to these comments and a few oxidation ditch plants have been removed from service because of operational problems. These cases are the exception.

The most serious process operation difficulties resulted from equipment related problems.

Many of the plants visited were manned only during a single shift and, in many cases, for only a portion of a single shift. A number of plants received little or no attention during weekends. Assuming no mechanical malfunctions, the plants perform well for long periods (days to weeks at a time) with little or no operator attention. Most plants practiced regular or periodic sludge wasting. In some cases sludge wasting was not practiced, but this caused eventual or regular carryover of excess solids in the effluent.

Almost without exception, operators and administrative personnel were well satisfied with the plants. In most cases the plants were meeting state discharge requirements.

A study of EPA Region VII(6) of winter performance of secondary wastewater treatment facilities concluded "...in general, the facilities were not meeting the secondary treatment effluent definition on the average except for the oxidation ditch subset".

All plants visited exhibited good mixed liquor characteristics (by visual observations). Some plants reported more than desired carryover of solids in the effluent and it is believed that the cause was either excessive oxygenation of poor management of sludge return wasting.

Many plants could reduce the level of oxygenation in the aeration basin without detrimental effect and reduce energy cost. There were no signs of lack of oxygen. One plant was cycling the aerator one hour on and one hour off and reported excellent results for over a year. Several other plants were considering this scheme to lower operating costs and reduce oxygen levels.

When screening or comminution is not regularly and properly carried out, rags and debris tend to cause problems in the plant expecially in the return sludge system.

One deep type (10 feet) single channel plant reported poor mixing in the ditch.

A number of plants lacked sufficient drying bed capacity which may have led to erratic sludge wasting practices. This problem was also reported by EPA Region VIII personnel.

A number of plants lacked proper laboratory facilities and equipment. Some even lacked a building. These facilities are necessary for proper operation and maintenance of a wastewater treatment plant.

As with any plant containing mechanical equipment, oxidation ditch plant equipment was subject to problems, malfunctions, and failures. As a general observation, oxidation ditch plants are capable of long periods of operation without mechanical problems and appear to operate with a very high mean time between equipment failures, particularly with proper preventative maintenance and inspection programs.

The following is a general summary of mechanical problems as related by plant personnel.

1. Some plant personnel reported that drives trip out on momentary electrical failures and do not restart upon restoration of power. This causes problems with unattended operation and consideration should be given to maintained-contact type electrical control for drives such as lift pumps, aerators, sludge return pumps, and other items in cases where plants operate unattended. Time delays can be provided so all drives do not restart at the same time.

2. Some troubles were reported with return sludge pumping. In general, centrifugal, non-clog pumps seemed to give good service especially when a separate potable grade seal water source was used. Air lift pumps were not common as would be expected at plants with mechanical aeration. A number of plants returned sludge by gravity to the raw sewage lift station and pumped it to the ditch with the raw sewage. This increased the size of the lift pumps, but eliminated one set of pumping.

3. Comminutors were a continuing maintenance problem. They required regular cleaning and care. Some operators had so many problems they stopped using the comminutor and allowed unscreened sewage to flow into the ditch. Almost without exception this caused problems in the return sludge system by clogging the sludge return rate adjustment valve (generally a telescoping valve)

or pumps. This altered the sludge return rate and caused process problems if not detected early. Oscillating type comminutors appear to give best service, but still require regular maintenance.

4. Access walks should be designed to avoid receiving spray from aerators even under various wind conditions. This spray creates hazardous conditions because of algal growths and freezing. This oversight created continuing maintenance problems and should be considered in all designs.

5. Sludge reportedly settled in channels at some plants where flow control walls were not installed as recommended by manufacturers.

6. There are some reported corrosion in final clarifiers which resulted in materials failures (bolts in particular). These units should be drained and inspected annually. Any corrosion should be removed and the area recoated.

7. Weirs are a maintenance problem and must be cleaned frequently; in some cases as often as daily.

8. Aerators and aerator drives account for a major portion of the mechanical problems. Most plants experienced the following aerator related problems every two to five years per aerator unit.

   a. Loss of some "teeth" from brush type aerators due to corrosion of bolts or damage sustained while handling the aerators is a common occurance. This generally is not a serious problem and can be repaired during periodic shutdowns. Some manufacturers have redesigned their aerators to minimize this problem.

   b. Bearing problems were reported in gear drives, line shafts, and aerator shafts. Experience whould seem to indicate a bearing problem every 2 to 5 years per aerator. These problems result from poor selection of bearings, constant splashing of water onto the bearing, improper initial alignment, differential settlement of bearing support structures and similar problems. Some manufacturers have taken steps to reduce bearing problems by using self aligning bearings, double seals, and by providing water shields, but bearing problems can still be expected. The magnitude of the bearing problem is not excessive and normal plant maintenance programs can handle this problem.

   c. Flexible couplings between line shafts caused problems on multiple concentric ring type plants.

   d. At one plant some of the disc aerators loosened from the shaft and had to be shimmed and reclamped.

e. Gear reducer output shaft seals need replacing about once a year at some plants.

f. There are a number of plants where gear reducer failure was experienced within a year of plant startup. This was probably due to improper initial alignment or differential settling of the aerator support structure.

g. A couple of plants have experienced aerator torque tube failure or excessive deflection with very long aerators. At one plant the tube failed, collapsing in the middle. One consultant not requires solid shafts on all aerators rather than hollow torque tubes. It may be well to avoid the use of very long aerators. If a wide ditch is necessary, the width can be spanned using two shorter aerators driven by a common drive.

h. Protective covers around bearings, couplings and drive units are not provided at most installations. Spray from the aerators keeps these components wet and possibly contributes to short life. The "slingers" at each end of the aerator are ineffective because wind blows this "tail" of water sideways onto adjacent components such as bearing and drive units. Corrosion and grit on shafts probably contributes to short seal life. For maximum service life and minimum maintenance these components should be shielded from water spray. Some manufacturers are taking steps to modify their standard designs to provide spray baffles and shields.

i. Some drive configurations require the aerator to be lifted out of position to remove the gear drive. This is a difficult operation requiring a crane. Access for a mobile crane should be provided to all aerators or other lifting provisions designed into the plant.

Cold weather problems related to oxidation ditch plants appear to be minimal except in severe climates. Those which have been identified are listed. These comments are based on visits and literature.

1. Final clarifiers should be covered where this is typical practice for other types of plants.

2. In moderately cold areas the spray from aerators will freeze on adjacent structures, bearings, gear reducers, and like equipment making maintenance difficult. Drive components should be covered to provide shielding from spray or these drives mounted in isolated compartments.

3. In moderately cold areas some problems were reported from ice build-up on clarifier scum collection boxes and eventual jamming of skimmer mechanisms.

4. Problems were reported with freezing of spray around aerators. The problem is solved by covering aerators in moderately cold areas, providing heated covers in very cold areas, and providing heated buildings over the aerators or over the whole ditch in extremely cold areas. When installed inside buildings, a shield should be provided over aerators to control spray.

5. In areas with periods of very cold weather all equipment requiring regular maintenance or service should be housed.

6. Poor mixed liquor settling was experienced during winter months at several plants in cold weather locations. This was probably due to filamentous growths resulting from the low winter loadings.

Waste activated sludge handling requirements depend on the plant design and operation. Plants operated with a 24-hour channel hydraulic retention time at 20 to 30 day SRT produce a biologically stable waste sludge that can be handled without causing significant odor problems. Plants operated with 6 to 8 hour channel hydraulic retention time and less than 10 day SRT require additional sludge treatment, typically aerobic digestion. Some problems have been noted in dewatering activated sludge directly on sand beds from plants operated at a 24-hour hydraulic retention time. These sludges tend to dewater very slowly requiring significantly increased sludge drying bed area. In areas where wet and cold weather are common, sludge drying bed area should be even larger. Some plants are operated indefinitely without formal sludge wasting allowing solids to build up in the aeration channel. This type of operation is considered marginal because the plant is prone to periodic clarifier upsets resulting in high final effluent solids.

CONCLUSIONS

Oxidation ditch plants are capable of consistently achieving high levels of BOD_5 and TSS removals with minimum operation. High levels of nitrification (95%-99%) are possible with proper operation. Nitrogen removals as high as 80% can be achieved in a single channel plant with careful operation of the aeration equipment to produce aerobic and anoxic zones within the channel. Increased operator attention is required to produce the high levels of nitrogen removal.

REFERENCES

1. McKinney, R.E. Mathematics of Complete Mixing Activated Sludge. Trans. Amer. Soc. Civil Eng., 128, Part III, Paper No. 3516 (1963).
2. Eckenfelder, W.W., Jr.; O'Connor, D.J. Biological Waste Treatment. Pergamon Press, Oxford, England (1961).
3. Monod, J. Research on Growth of Bacertia Cultures. Herman et Cie, Paris (1942).
4. Goodman, B.L.; Englande, A.J. A Unified Model of the Activated Sludge Process. Journal Water Pollution Control Federation, 46, 2, p. 312, February, 1974.
5. Goodman, B.L. Monod Type Relationships Applied to Complete Mixing Activated Sludge. Unpublished, January 25, 1973.
6. Draft Report. Winter Performance of Secondary Wastewater Treatment Facilities. EPA Region VII.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

PAPER NO. 14

PERFORMANCE AND DESIGN OF RBC PROCESSES

by

Warren H. Chesner
Partner

Engineering Consultants & Associates
Fort Lee, New Jersey 07024

PERFORMANCE AND DESIGN OF RBC PROCESSES[1]

Warren H. Chesner, Partner
Engineering Consultants & Associates
Fort Lee, New Jersey

INTRODUCTION

Rotating Biological Contactor (RBC) Systems have been in operation in this country treating municipal wastewaters for more than ten years. Over 260 municipal wastewater installations were in operation as of 1979 with design flowrates ranging from 0.01 mgd to 54 mgd.

RBC performance in terms of treatment efficiency, power requirements and equipment have been almost exclusively defined by equipment vendors. Vendors have provided design curves for both carbonaceous and nitrogenous removal, recommendations for stagina and flow distribution, projected power consumption and media, shaft and drive requirements.

During the operating history of RBC's in this country, additional information has become available through the literature and through the collection of plant data from which to evaluate RBC performance and design. This historical record has revealed relevant information which should assist the designer, operator and vendor in evaluating, designing and operating RBC systems.

CARBONACEOUS BOD PROCESS PERFORMANCE AND DESIGN

A comparison of cumulative performance versus vendor design guidelines for sixteen RBC facilities approaching design flow revealed that RBC performance was less than that predicted by vendor design recommendation for average influent municipal wastewater concentrations ranging from 97 to 214 mg/l BOD, with hydraulic loadings in the range of approximately 0.5 to 3.0 gpd/sf (1).

1. The absolute value of the vendor curves are based upon field data accumulated at specific locations which may not reflect RBC performance elsewhere.

2. Plant performance is the result of a series of unit processes. Poor secondary clarifier performance would adversely effect recorded RBC performance.

3. Operation and maintenance practices at specific plants influence overall plant performance which would reflect upon RBC performance.

---

[1] Presentation based on a study by Roy F. Weston, Inc. for EPA MERL.

Some of the specific process problems the facilities encountered were the result of one or more of the following:

1. Unanticipated sidestream loadings
2. Low influent concentrations
3. High organic loadings

Unanticipated sidestream loadings such as return supernatant from sludge treatment processes or septage disposal can result in organic overloads to the RBC system. These can be corrected by planning for the additional load by either increasing the RBC treatment capacity or better equalizing the sidestream flow to the system.

Low influent concentrations (less than 100 mg/l raw BOD) are common in sewerage systems with inflow/infiltration problems. Lower organic concentrations with altered wastewater characteristics and treatability result in reduced performance. The solution to these problems again rests with proper facility planning with respect to anticipated wastewater conditions.

High organic overloads is a problem resulting from oxygen deficiency within the biofilm. This condition can result in the competitive growth of nuisance organisms and reduced organic removal rates. The condition which results in an organic overload is dependent upon many factors. For a given media, these include rotational speed, influent flow distribution, organic concentration, and flowrate.

Rotational speed influences the film thickness, the aeration of the reactor liquid as well as the residence time per rotational cycle that the biofilm is exposed to the atmosphere and the reactor liquid. Too slow a speed can result in excessive residence time in the liquid, with little oxygen available.

Proper influent flow distribution is necessary to evenly distribute the influent flow and loading to all parts of the media, and to avoid overloading individual shafts or portions or shafts.

Organic concentration and flowrate jointly determine the organic load. Individually organic concentration determines the mass transfer driving force, and flowrate the reactor or treatment retention time. The greater the organic concentration, the greater the demand for oxygen. The greater the flowrate, the shorter the retention and the higher the reactor organic concentration adjacent to the biofilm.

Organic overloads typically occur in the initial stages of RBC systems. One vendor (2) presently recommends a maximum first stage organic loading of 4.0 pounds of soluble BOD per day per 1000 sf of media to avoid overloading in mechanically driven systems. A review of twenty-three facilities around the country with and without the reported presence of organic overloads for 12-foot diameter discs operating at rotational speeds of approximately 1.6 rpm revealed a first stage loading of 6.4 pounds of BOD (total) per day per 1000 sf as the first stage loading beyond which organic overloads were reported (1).

EQUIPMENT AND MAINTENANCE

RBC equipment can be subdivided into various components: media, shaft, bearings, drive and media supports (radial arms).

Each vendor offers media with their own unique configuration. In general, there are two types of media: standard and high density. Standard density contains approximately 100,000 sf per 25-foot shafe, and high density which is packed more tightly contains 150,000 sf per 25-foot shaft. Disc media is constructed by extruding high density polyethylene into individual sheets which are subsequently formed into the desired surface configuration. These individual sheets are cut into pre-shaped segments each representing one-eighth of the total circular disc. Some manufacturers group the pre-shaped slices together to form a wedge of media held in place by penetrating rods or straps. The wedges are supported by steel arms radiating from the shaft. As the shaft rotates, the steel arms in turn rotate the media. A second method of construction is a unitized self fupporting plastic disc, mounted on and driven by a square shaft. In this case, the pre-shaped pieces are connected to form circular plates that are welded together and mounted in the shaft. A reinforced hub provides the transfer of drive from the shaft to the media. A third type recently introduced consists of strips of high density polyethylene which are vacuum formed, spirally wound and heat welded in a continuous wrapping process on a circular shaft.

The RBC shaft and media can be driven directly by motor (most commonly rated at 7.5 hp) or by recently introduced air drive systems which make use of the buoyant force of compressed air released into the reactor to drive the disc.

A survey of equipment history in RBC facilities (1) revealed significant problems with respect to the reliability of certain components of the system. A summary of the results of this survey are presented in Table 1.

The results indicate an unusually high percentage of shaft failures (8.5%), with almost all occurring in the first stage where higher loadings and heavier growth occur. Bearing problems were not significant, but reported radial arm problems (30%) were high. Reported medial problems were most commonly reported in radial arm facilities (80%), the result of a shifting of the media, relative to the radial arm. Drive problems were not major. The average years of operation prior to reported problems were low in all cases, which is indicative of design deficiencies as opposed to normal equipment wear.

Solutions to equipment problems rests with both the vendor and the engineer to insure that the equipment is specified properly and utilized within its design limitations.

A survey of maintenance requirements, presented in Table 2, revealed little manpower requirements directly attributable to RBC maintenance or process control.

TABLE 1. RBC EQUIPMENT SURVEY

Equipment	No. of Facilities Surveyed	Reported Failures	Percent Reporting Failure	No. of Shafts	Shaft Failures	Percent Shaft Failures	Average Years Of Operation At Failure
Shaft	17	7	41	141	12*	8.5	1.9
				No. of Bearings	Bearing Failures	Percent Bearing Failures	
Bearing	17	3	18	282	8	3	3.3
				No. of Shafts	Radial Arm Failures	Percent Radial Arm Failures	
Radial Arm	4	2	50	23	7	30	2
Media	17	5**	29	--	--	--	2
				No. of Shafts	Chain Failures	Percent Chain Failures	
Drive	17	3	18	141	8	6	2.3

---

* Of the 12 reported shaft failures, 11 occurred in the first stage.

** Of 5 facilities with media problems, 4 were radial arm type.

TABLE 2. MAINTENANCE REVIEW

No. of Plants Surveyed	No. of Shafts	Equipment Maintenance Man-Hours Per Week
20	2-8	0.25-7
4	10-48	3-13

POWER PERFORMANCE

Energy utilization is rapidly becoming the major O&M item in many wastewater treatment facilities. Selection of processes with low energy requirements is a major priority. A power survey of seven mechanically driven systems revealed an average power requirement of approximately 3.4 kw for a 25-foot shaft with standard density media and 3.8 kw for a 25-foot shaft with high density media. Table 3 presents the results relative to reported vendor values.

TABLE 3. MANUFACTURER POWER ESTIMATES AND FIELD OBSERVATIONS

Manufacturer	Power Requirements (kw)	
	Standard Media	Hi-Density Media
Autotrol	2	3
Clow	2.4	2.6
Hormel	2.3	2.6
Walker	2.5	3.1
Average Field Observations	3.4	3.8

Energy utilization will vary from stage to stage in RBC facilities with the initial stages utilizing more energy than the latter stages. This was judged to be due to the greater friction resulting from heavier growth on the media. Power requirements were also found to be proportional to the third power of the rotational velocity, which limits the cost effectiveness of increased rotational speed to enhance treatment performance.

CONCLUSIONS

The operating history of RBC facilities has revealed design limitations with respect to organic overload, a suspect record with respect to equipment problems and higher than anticipated power requirements. Additional care is warranted in the selection and the design of the RBC process for municipal wastewater treatment. Sufficient facility information is available for designers to assess the loading requirements, equipment history, and power requirements of the process. Vendors must address equipment deficiencies which should not be limiting to RBC performance.

REFERENCES

1. Review of Current RBC Performance and Design Procedures; EPA-MERL; to be published in 1982

2. Autotrol Design Manual; 1979

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

SESSION NO. 5
Energy Conservation in Municipal Wastewater Treatment

PAPER NO. 15

ENERGY CONSERVATION IN UNIT PROCESSES
AND SLUDGE MANAGEMENT

by

Daniel Cortinovis
Operating Services Department

Brown and Caldwell
Walnut Creek, California 94596

ENERGY CONSERVATION IN UNIT PROCESSES AND SLUDGE MANAGEMENT

DANIEL CORTINOVIS, OPERATING SERVICES DEPARTMENT
BROWN AND CALDWELL

INTRODUCTION

The key link between a valid design concept for energy-efficient wastewater treatment and the realization of that goal is the treatment plant operator. His understanding of the processes and equipment systems and his ingenuity in dealing with changing conditions make energy conservation and recovery possible. He needs a grasp of the interrelations between unit processes and their costs in dollars and energy so he can fine-tune the plant to optimize the use of our resources.

All of the wastewater treatment plants in the United States consume only about 0.25 percent of the nation's electricity, but that amounts to several hundred million dollars worth of energy. As this figure increases and energy supplies continue to dwindle, more emphasis is being directed toward energy conservation in plant design and operation.

Since most treatment facilities depend largely on electricity as their source of energy, this paper will begin by defining in general how power rate schedules are set up. Treatment plant operators need to understand the methods used to compute the plant's power bill so that they can direct their energy-saving efforts toward cost-saving as well.

Examples of energy-conservation techniques used in various plants are described using generalized case examples. The operator's role in optimizing the use of energy is the focus of these discussions, with emphasis on areas such as biological treatment, solids handling, and energy recovery. The intent of this presentation is that operators will relate these examples to situations in their own plants to aid them in devising programs for conserving energy.

POWER RATE SCHEDULES

In past years, before there was commonly thought to be an energy crisis, large users of electrical power received discounts as their consumption increased. This encouraged industrial growth and increased power generation by the utilities. Because of regulatory pressure and the increased emphasis on conservation, rate schedule structures have not been drastically revised.

A. Energy and Demand

Energy is defined as the quantity of power used per unit time, measured as kilowatt-hours (kWh). Demand is an instantaneous measurement of the power being used at any particular time. It is measured in kilowatts (kW), which can be related to the effective horsepower of the equipment in operation at the time.

An energy charge is made for each kWh used to pay the utility's operating costs for generating the power. A demand surcharge may also be assessed each billing period, based on the maximum demand sustained throughout a specified time interval such as 30 minutes. This surcharge pays the capital costs for having generating capacity available to meet the demand.

B. Time-of-Day Demand

In areas where the demand threatens to exceed power production capacity at certain times, a sliding scale is being used to adjust the demand surcharge to the time of day and the season. This is intended to discourage large customers from creating a high demand during peak times, such as summer afternoons when a large number of air conditioners are running.

Some manufacturing operations are probably able to adjust their production schedules to avoid peak demand periods, but doing this in a wastewater treatment plant requires a lot of ingenuity because of the lack of control over incoming flow and loadings. However, some possibilities are:

1. Flow storage prior to treatment.
2. Shutting down solids processing during demand peaks and catching up later.
3. Storing digester gas or other fuel and generating power during peak demand periods.

An example of a peak-period demand surcharge schedule for a plant with a monthly demand greater than 4,000 kW is shown below.

Demand charge per kW	Summer	Winter
On peak (early summer and late winter afternoons)	$4.20	$2.80
Partial peak (mornings and evenings)	0.35	0.35
Off peak (nights, Sundays, holidays)	None	None

C. Other Charges

Several other factors which affect the dollar amount of the monthly power bill are:

Customer charge--A flat rate service charge for each metered connection as assessed.

Voltage adjustment--Customers taking delivery at voltage higher than 2 kV may get a demand charge discount.

Power factor--The ratio of lagging kilovolt ampere hours to kilowatt hours consumed increases or decreases the total bill, depending on how much it deviates from a specified ratio (usually about 0.85).

Facility charge--If the utility spends more constructing service facilities for a customer than they receive in revenue, an additional charge may be made as a percent of the excess.

Energy cost adjustment--A variable charge per kWh is made to cover changes in the cost of fuel used to generate power.

ENERGY-SAVING TECHNIQUES

Specific methods for trimming energy costs are outlined below, using generalized case examples based on actual operating plants. With some techniques, the cost savings result from reduction in demand peaks. In most cases, an overall reduction in energy consumption is the primary method of saving money. The most important aspect of an energy conservation program is a total system approach. For each operational change initiated to save energy, the whole facility must be considered to ensure that a corresponding increase does not occur in another area.

A. Power Monitoring

Relatively inexpensive instrumentation is now available for constant monitoring of both energy use and demand. Installation of monitoring equipment at the plant's incoming substation and at individual motor control centers supplies on-line information to the operations staff, telling them how much power is being used in which areas. This information is essential, especially if time-of-day demand peaks are being shaved through operational modifications. Where digital computer systems (or even small microprocessors) are available, the data can be trended and totalized to aid in interpretation and record keeping.

B. Unit Capacity Optimization

Plant managers should carefully evaluate process operations to determine when treatment units should go in and out of service, especially in plants where the load changes seasonally. Although short-term fluctuations in loading may not dictate changes, anticipation of and response to seasonal variations can save significant amounts of energy while still maintaining effluent quality. Accurate judgments are required--for instance, cutting back on anaerobic sludge digester mixing may save only minimal amounts of energy while causing a disastrous upset. In contrast, secondary treatment units such as activated sludge aeration tanks and high-head oxidation towers are very energy intensive and should not be operated far below design capacity. Clarifiers, on the other hand, require a very small amount of power and may enhance treatment efficiency when multiple units are operated at low overflow rates.

A municipal secondary treatment plant using high purity oxygen activated sludge was designed for 120 million gallons per day (mgd). The flow configuration uses 8 biological reactor trains and 12 clarifiers. Although the nominal design flow for each reactor train is 15 mgd, the oxygen dissolution capacity is adequate for at least twice that to handle seasonal load increases and a possible future requirement for nitrification. Since each of the eight trains uses 400 horsepower (hp) of mixers, a significant energy savings is realized by operating only three or four trains for the actual average dry-weather flow of 80 mgd. All available clarifiers are used, since they have only 1-hp drive motors. During low loading periods, mixers on some stages can be shut down, saving up to $5.00 per hour each.

C. Aeration Blower Control

In most conventional activated sludge plants, the largest consumers of energy are the blowers or mechanical devices used to supply air to the aeration tanks. Many plants in past years were designed with strictly manual control of the aeration system, due to the following factors:

1. Reliable on-line instruments for measuring the dissolved oxygen (DO) level of the mixed liquor in the aeration tanks were not yet available.

2. The cost of energy was much lower than now, as compared to the relative cost of instrumentation systems.

3. The state of the art of activated sludge process control was less advanced.

Now that energy costs are high and DO control systems fairly reliable, the majority of new plants are being designed with these control systems and many agencies are adding them to their existing plants. Although there have been some attempts to control mechanical aerators by DO level, most of the current systems use diffused aeration with suction-throttled centrifugal blowers. An electrical signal from the DO probes in the tanks is usually converted to a pneumatic signal which controls automatic air distribution valves on the headers to each aeration tank pass. A pressure sensor on the blower discharge manifold upstream of the distribution valves controls the inlet guide vanes on the blowers to maintain a constant pressure in the manifold. Analog or digital control loops can be used.

The energy consumption is reduced with DO control because centrifugal blowers use less power when the suction is throttled. The turndown limit (surge point) is usually about 50 percent of design capacity, so several blowers of different sizes may be used to provide a better coverage of operating ranges. The activated sludge process is subject to upset at low DO levels, so controlling the DO at higher levels for higher loadings protects effluent quality.

Many oil refineries have activated sludge systems for treatment of their process wastewater. For two systems which originally used single-speed mechanical aerators with no control systems, studies showed that installation of completely new aeration systems using DO control with diffused air and centrifugal blowers could save enough in power costs to pay for the new equipment in several years. Some particular considerations which contributed to this analysis were:

1. Due to the cyclic nature of refinery processes, the incoming waste load varies widely over periods of short duration.

2. The temperature of the wastewater is unusually high which cuts into aeration efficiency and makes a more efficient system more cost-effective.

D. On-Site Power Generation

The current emphasis on the environment and energy has focused attention on the production of "bio-gas" from digesting organic matter. Municipal waste treatment plants have used the anaerobic digestion process for over 50 years to stabilize sludge before utilization or disposal. The gas produced, containing about 65 percent methane, has been used in boilers to produce heat for the digesters and plant site buildings. In some larger plants, the excess gas is used to generate power.

One problem with using digester gas for power generation is the high initial capital cost and high maintenance costs for large reciprocating engines. Another problem, particularly with primary plants, has been that the greatest excess of gas is available in the summer, when heat requirements are less and power requirements lower due to decreased flows. Experience with engine-generator design and the development of gas turbines have helped to minimize maintenance costs. Some plants expanded to secondary treatment have found a drastic shift in their seasonal energy requirements, with summer peaks occurring for biological treatment of food processing wastes. The advent of cogeneration, where induction generators are operated in parallel with utility power, will also contribute to the cost effectiveness of installing on-site power generation systems.

A 55-mgd primary and secondary plant located in a largely agricultural area treats a mixture of domestic sewage and seasonal cannery wastes. Methane gas from anaerobic digesters is used to fuel three piston engines driving variable-frequency generators. Two generators power the effluent and effluent pumps using the variable-frequency feature to control pump motor speed. The third unit powers other plant equipment when extra gas is available. In 1980, 36 percent of the power used in the entire plant was generated on-site at a savings of over $150,000. Hot water from the engines' cooling system is circulated through a reservoir loop to heat the digesters and plant buildings.

E. Heat Reclamation Systems

Heat is produced in some treatment plant processes while being required in others. Waste heat can be recovered in large quantities from incinerators boilers, and engines. It is transferred in water to heat sludge digesters and plant buildings or in steam to power turbines driving mechanical equipment. Operational control is critical because the systems are often complex, with the balance between heat requirements and availability constantly changing as changes occur in plant load, flow, and ambient air temperature.

One type of system uses a hot water reservoir loop to circulate waste heat from digester gas-powered engines to digester and building heating systems. Thermostatically controlled valves and pumps regulate the flow of water to the various units. A balance in the system is maintained by disposing of excess heat in exchangers located in the wastewater flow stream. In emergencies, heat from auxiliary boilers or resistance-type electrical heaters is added. Because no automatic system can anticipate changes in variables such as digester gas availability and ambient temperatures, the experience of the operators is relied upon for judgments as to when engines should be started or control set points changed.

F. Solids Handling Trade-Offs

The push for secondary treatment expansions mandated by the 1972 Water Pollution Control Act often resulted in a decrease in emphasis on solids handling and disposal. Now that many new secondary plants are on line, the full impact of increased sludge production and changes in its characteristics are being realized. Processing and disposal or utilization of solids is rapidly becoming the most cost- and energy-intensive aspect of wastewater treatment, especially as urban sprawl increases the distance between treatment plants and land areas available for disposal.

The operator's success in reducing the overall amount of energy consumed in solids handling processes will depend on his recognition of the relationships between trade-offs in which he can make choices. Some examples of these follow:

1. Vacuum or belt filters are very energy-efficient devices for dewatering some types of sludges. Correct chemical conditioning of the sludge is critical and relates to energy use because higher production and lower moisture content mean shorter running time for equipment and lower offhaul costs.

2. The use of centrifuges for dewatering digested primary and secondary sludges is becoming more common because of the difficulty in thickening these sludges. When centrifuges are operated at a low capture, the operator may have the illusion that he is producing a lot of cake at a low chemical dosage. He should realize that the cost and energy penalty is high for this because solids recycled through the plant have to be retreated and reheated in the digesters before he gets another chance to remove them. In-plant solids recycle is also a major cause of effluent quality degradation.

3. When sludge is to be incinerated, dryness is usually of paramount importance because large amounts of supplemental fuel are required when excess water is fed to the furnaces. Most dewatering equipment will produce a drier cake at lower throughput, so it becomes the responsibility of the operations staff to operate more dewatering units on a longer schedule if the trade-off is favorable.

4. The difference between being able to use a low-energy land disposal or composting operation or a higher technology, more energy-intensive alternative often depends on the operator. He can ensure

adequate sludge stabilization through efficient process operation and develop favorable public relations by taking prompt action on odor and nuisance problems.

G. Pumping and Hydraulics

Operators cannot be expected to redesign the hydraulic profile of a treatment plant, but they can often save energy by making some simple adjustments. The approach of the design engineer is usually to conserve as much pumping head as possible in equipment and structure design, since it is estimated that each foot of head will cost about $500 per year per mgd in energy. However, the design must allow operational flexibility and leave room for possible future expansion, so pumps are sometimes oversized and head losses designed in.

Treatment units such as synthetic media oxidation towers (modern version of the "trickling filter") depend on recirculation pumping for aeration and contact between waste and microorganisms. Using frequent loading rate calculations, the operator can adjust the recycle rate to the minimum necessary to maintain process efficiency. Excess recirculation only wastes energy and will not increase removals. This also applies to return activated sludge pumping. It may be easier to crank the pumps up to high speed and forget about them, but careful sludge blanket monitoring will result in an increase in solids concentration, which will allow lower pumping rates.

SUMMARY

1. Wastewater treatment plants in the United States depend primarily on electrical power as a source of energy, consuming about 0.25 percent of the nation's total.

2. The size of the monthly power bill depends on the amount of energy used and the magnitude of the demand, as well as several other factors.

3. Plant operators need to understand the energy interrelationships and individual impact of variables under their control so that they can fine-tune the treatment processes to reduce energy consumption.

4. Some energy saving programs and techniques currently in use are:

   A. Shaving demand peaks by careful operations scheduling.

   B. Optimizing process units to reduce the amount of equipment in service.

   C. Aeration equipment control automation by dissolved oxygen level.

   D. Power generation using gas from sludge digesters.

E. Reclaiming excess heat from mechanical systems, such as engines and incinerators.

F. Evaluation of solids handling energy trade-offs.

G. Conservation of hydraulic head.

"The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred."

PAPER NO. 16

A COMPOSITE APPROACH TO ENERGY CONSERVATION
THROUGH PROCESS OPTIMIZATION

SOME CASE STUDIES

by

Ashok K. Singhal, P.E.
Vice President/Treasurer

and

Phillip N. Loud
Engineer

and

Donald W. Lystra, P.E.
Vice President

Ayres, Lewis, Norris & May, Inc.
Ann Arbor, Michigan 49481

A COMPOSITE APPROACH TO ENERGY CONSERVATION THROUGH PROCESS OPTIMIZATION
Some Case Studies

Ashok K. Singhal, P.E., Vice President/Treasurer; Phillip N. Loud, engineer; and Donald W. Lystra, P.E., Vice President
Ayres, Lewis, Norris & May, Inc., Ann Arbor, MI

INTRODUCTION

Municipal wastewater systems are heavy users of energy, not only directly through the use of electricity, natural gas, and other fuels but indirectly through the use of large quantities of chemicals produced by energy-intensive manufacturing processes. Table 1 summarizes energy consumption for the manufacturing of the various chemicals used for wastewater treatment. A recent study by the U.S. Office of Water Research and Technology showed water and wastewater systems to be the largest single component of energy consumption by local units of government, averaging about 25 percent of the total municipal energy use (1). Moreover, recent utility rate studies have shown that the direct energy costs of wastewater systems account for fully 20 percent of their total operating budgets (2).

During the past three years, Ayres, Lewis, Norris & May, Inc., (ALNM) has performed energy audits for eight wastewater treatment facilities in Michigan. This paper summarizes the findings of the energy audits. The main objectives of these audits have been threefold:

- to establish energy consumption profiles of the buildings and the treatment processes;
- to identify, analyze, and rank cost-effective retrofit measures and operational and maintenance strategies which will conserve energy;
- to develop an on-going energy management program.

ENERGY AUDIT METHODOLOGY

An energy audit is defined as a critical examination of an energy-consuming facility for the purpose of identifying energy conservation opportunities. Because of the overall complexity of wastewater facilities and the various technical specialties represented by their processes and equipment, the audits were broken down into smaller components. This made it possible to create specialized audit packages that could be addressed by team members from appropriate technical fields. The following subsystems were identified.

Treatment System: all processes and equipment used to treat wastewater and render it suitable for discharge into the receiving stream.

Capacity Control System: equipment used for pumping wastewater at various points in a treatment process.

Heating, Ventilating, and Air Conditioning System (HVAC): equipment that provides the control for the internal environment of buildings, including the building envelope itself.

Electrical Systems: equipment that distributes electricity to plant loads and provides artificial illumination for the interior and exterior of the facility.

An auditing team of technical specialists in civil, sanitary, mechanical, and electrical engineering, as well as architecture, was created to perform the energy audits at each of the study sites. The auditing procedures involved a review of existing documents and records, site visits, operator interviews, identification of energy conservation opportunities (ECOs), analysis of ECOs, and reporting.

Audit team members were instructed to look for ECOs in the following general areas: changes to operational and maintenance strategies; equipment changes (i.e., same function, different device); design changes (i.e., different function, different device); and relaxation or modification of design standards.

DESCRIPTION OF STUDY SITES

Table 2 summarizes design capacity, service area population and the type of treatment for the eight sites studied. All facilities rely primarily on electricity and natural gas for their energy requirements except Ann Arbor which also uses fuel oil. Electricity is typically used as the energy source for motor drives and illumination, whereas natural gas is used as the energy source for building heat, water heating, digester heating, sludge incineration, and chemical pretreatment.

The breakdown by energy source of total energy consumption at each study site is given in Table 3. The breakdown of energy consumption for each site within the four functional subsystems is shown in Table 4. In general, more than half of the energy used by the wastewater facilities is for treatment equipment and relatively little for pumping. The total energy consumption and energy cost per cubic meter of water treated at each of the facilities is given in Table 5. As shown in the table, these costs vary from $57 per million gallon at Wyoming, Michigan, to $133 per million gallon at E. Lansing, Michigan.

PROCESS OPTIMIZATION

In the process of identifying energy conservation opportunities at the wastewater treatment plant sites, it was recognized that the treatment systems account for 50 percent or more of the total energy consumed at a wastewater plant. As shown in Table 4, at the eight sites studied, treatment systems accounted for 44 percent of the total energy consumed at Wyoming, Michigan, to 75 percent at Ann Arbor, Michigan. In addition, treatment systems also utilize considerable amount of chemicals which have an indirect impact on energy consumption through manufacturing and transportation. Therefore, it was recognized that process optimization should be a very integral part of an energy audit plan at a wastewater treatment plant. Process optimization would serve a dual purpose of conserving energy, as well as chemicals.

A six-step model for treatment process optimization used during the energy audits is summarized in Table 6. The first step is to review historical records from a treatment plant to establish the present plant performance in terms of influent water quality parameters, chemicals used, and process performance parameters for each of the unit processes. This information is generally obtained from the monthly operational summary sheets submitted to the State regulatory agencies. The data is summarized both graphically and in tabular form to establish trends and history. Figure 1 provides a summary of operational records for the Cadillac, Michigan, Wastewater Plant as an example.

The second step is to compare the plant performance parameters with the expected design performance for each unit process. In this process, a comparison of the actual plant efficiencies is made with the expected design efficiencies. In addition, during this stage, marginal utilities of adding various chemicals in the processes are also established. Marginal utility is defined by the following equation in reference to Figure 2:

$$\text{Marginal Utility} = \frac{\Delta y}{\Delta x}$$

where Δy = incremental removal of a pollutant
Δx = incremental cost of the chemical to remove a pollutant

In general, the idea is to add a chemical to a point where the marginal utility is one, or more than one. If from reviewing the historical records, it is found that the marginal utility for some of the chemicals is considerably less than one in actual plant performance, it would be an indication of gross process inefficiencies and deficiencies. Thus, Step 2, would generally provide a fairly good idea regarding the processes that are performing less than optimally.

The third step in the process optimization is to review the physical and chemical parameters effecting each unit process. The purpose of this step is to identify and pinpoint the reasons for poor performance of the unit processes identified in Step 2. As an example, at one of the treatment sites studied, ferric chloride was being added in the aeration system for phosphorus removal. Considerable amount of chemical was being used without achieving the desired 80 percent phosphorus removals. After reviewing the physical and chemical parameters associated with mixing and flocculation of the chemical, it was discovered that the aeration system was resulting in excessive shear velocities (G) resulting in G values of 130 to 150 sec^{-1}, thus breaking up the floc particles. As a result of the investigations, the chemical feed point was moved toward the tail-end of the aeration system and the amount of air was reduced to provide a shear velocity (G) of 60 to 65. This change resulted in a considerable improvement in phosphorus removals as well as the amount of chemicals used for phosphorus removal. Prior to initiating this change, 80 mg/l of ferric chloride was being used along with 0.5 mg/l polymer. Subsequently, ferric chloride dosage was reduced to 50 mg/l and the polymer was eliminated completely. In another instance, the chemical percipitation process was resulting in a poor floc formation during the winter months of operation. It was noted that fine pinpoint floc was being formed which was not coagulating properly. Investigations of the parameters effecting the flocculation process indicated that the plant had a fixed speed floc mixer providing adequate flocculation energy during the warmer months but was not capable of providing the necessary energy for flocculation during the colder months. It was noted that with the falling water temperatures, the viscosity of the wastewater went up by approximately 50 percent resulting in a similar increase in the power requirements for flocculation as shown by the following formula. A change in the flocculation process improved the results considerably.

$G = \sqrt{P/\mu V}$ where G=mean velocity gradient(sec^{1}),
P=power required(ft-lb/sec)
μ=absolute fluid viscosity (lb force-sec/ft^2), and
V=flocculator volume (cu ft)

μ at 20°C (58°F) = 1.009
μ at 5°C (41°F) = 1.519

The fourth step in the process optimization is to review alternate approaches for achieving process results in order to conserve energy as well as chemicals. The purpose of this step is to see if a particular process can be changed or altered to achieve the desired results at a lower overall cost. An example of this would be changing a chemical feed point in the process or using alternate chemicals. At one of the treatment sites, lime was being used for phosphorus removal. Because of the high hardness of the wastewater, a considerable amount of lime was being added to achieve desired 80 percent removals. Lime also produced large quantities of sludges. Replacement of lime with ferric chloride resulted in considerable energy and cost savings.

Once an alternate approach has been identified for a process, the fifth step is to conduct lab scale studies using alternate chemicals or process parameters for achieving the desired results. The purpose of the lab tests is to provide adequate data for evaluating cost effectiveness of a particular change being contemplated. It should be noted that the lab tests should reflect the actual operating conditions as closely as possible. For example, if a given treatment process is operating under low temperature conditions, the lab tests should also be performed under similar temperature conditions. Following the lab scale studies and a cost effectiveness analysis of alternate approaches being considered, a decision should be made regarding conducting full plant scale studies which is the sixth and final step. In conducting full plant scale studies, it is very important that process parameters be monitored very closely and be evaluated in terms of the changes that are being made. As a result of the full plant scale studies, if the proposed changes are found to be cost effective, they should be implemented.

IDENTIFICATION OF ENERGY CONSERVATION OPPORTUNITIES

In order to identify the energy conservation opportunities at the study sites, the following conceptual model of energy consumption was utilized:

Energy Source In
(e.g., electricity, gas)

Conversion System
(e.g., light bulb,
motor, boiler, etc.)

Function Out
(e.g., light, motion,
heat)

Energy Consumption Model

As the model illustrates, energy enters a conversion system and is transformed into a useful function. Therefore, there are three basic ways to conserve energy and/or cost which correspond to each phase of the model.

1. Use a Less Expensive Source:
   - change fuel
   - use off-peak electricity
   - use waste energy
   - use renewable source (solar, wind, etc.)
2. Increase System Efficiency:
   - improve performance
   - improve maintenance
   - change equipment
3. Modify Functions:
   - eliminate unnecessary functions
   - retain function but use less
   - substitute less expensive function

Based on the above conceptual model as a guide, energy conservation opportunities were identified at each of the study sites. These can be divided into low cost or no cost energy conservation measures and those requiring capital investment for implementation. Low cost measures are typically operational measures which cost less than $500 to implement and have a payback period of less than one month. The most commonly encountered low cost measures in each of the four functional areas are discussed below:

Architectural

Low cost architectural measures typically involve insulating, weatherstripping, caulking, and repointing. These measures generally serve to reduce infiltration or slow the rate of heat transfer through a structural membrane. These measures can be implemented by plant staff and result in savings in the annual heating load. Implementation costs for most facilities are generally $100 or less.

Heating, Ventilating and Air Conditioning

Three major low cost energy conservation measures in the HVAC subsystem are identified in almost every wastewater treatment facility. These measures include dialing down temperature settings, reducing outside air flow, and fine tuning boiler burners.

Dialing down plant thermostat settings plantwide from 72° to 68° will effectively reduce the plant heating load by approximately 9-10 percent. In many cases, certain areas can be heated to even lower temperatures providing even greater savings without any implementation cost.

Reductions in outside air quantities of 10-50 percent are typically proposed in wastewater plants equipped with heating systems utilizing mixing air boxes. These changes have resulted in heating load reductions of up to 20 percent.

Fossil fueled boilers are typically operated with too much excess air and potentially dirty heat exchangers. Inexpensive flue gas testing kits costing around $200 have been utilized to fine tune boiler operations to improve burner efficiencies by 2-4 percent. A plant with a $10,000/yr boiler fuel cost would pay for the test kit in one year with a 2 percent increase in efficiency.

Treatment Process Systems

Low cost operational changes to the treatment process systems which result in energy savings typically involve the operation of more efficient pumps, the reduction in chemicals fed through process optimization as discussed earlier, or a reduction in total aeration requirements.

Variances in operating efficiency of redundant pumps, identified during an energy audit, often result in a low cost measure recommending increased operation of the most efficient pump. Similar pump efficiencies may often differ by 3-7 percent depending on age and utilization. A three percent difference in efficiency for a 50 hp pump running continuously represents a potential savings of $960 annually ($0.05/kwh).

Reductions in quantities of chemical fed does not typically result in large direct energy savings. However, the secondary impacts on sludge production and process efficiency can potentially result in large energy savings.

Aeration systems in wastewater plants typically represent 30-60 percent of total plant electrical energy consumption. An analysis of the air requirements for several activated sludge plants has resulted in an identification of potential reductions in aeration levels of 12-27 percent at cost savings of approximately $3,000-$34,000 annually. Figure 3 shows an example of potential for reducing air at a wastewater treatment plant.

Electrical/Illumination Systems

The most common low cost energy conservation measures applicable to electrical/ illumination systems fall into the categories of lamp replacement, delamping, and fixture cleaning.

Many wastewater plants utilize standard fluorescent lamps for operating areas, as well as pipe galleries. Reduced wattage fluorescents typically consume 20 percent less power and cost approximately 33 percent more than standard bulbs. A program of replacing standard fluorescents when they burn out with reduced wattage bulbs provides energy savings capable of 6-month paybacks for each bulb.

Regular cleaning of fixture housings, reflectors, and diffusers can improve lamp efficiencies by as much as 35 percent. Clean fixtures operate at a lower temperature which can typically lengthen the life of a lamp by 25-30 percent.

Another potentially significant area of electrical cost savings is in electric billing structures. Communities who are currently on "flat rate" electric structures may qualify for "variable" rate electric contracts with their utility. Wastewater facilities often benefit from variable rate structures due to their inherent diurnally and seasonally varying electric demands. Cost savings ranging from 15-25 percent have been seen in our studies from simple contractual changes to variable rate structures incorporating on-peak, off-peak, and kw demand components into the billing.

Tables 7 through 10 summarize capital cost energy conservation measures for four of the treatment plant sites studied. In general, capital cost measures dealing with HVAC and illumination systems have the fastest payback period while the architectural items have the slowest payback. Treatment systems offering the greatest potential for conservation are related to sludge handling and disposal and aeration system modifications.

Based on the energy audit studies, the following is a checklist of potential energy conservation opportunities (ECOs) at a wastewater treatment plant.

Ventilation and Cooling System ECOs

- Close off unoccupied areas by blocking supply register
- Shut off system and open windows
- Raise cooling temperatures to 78° (non-reheat)
- Install ventilating equipment timeclocks
- Install ceiling fans in high bays
- Install local switches for exhaust fans
- Install economizer/enthalpy control
- Close air dampers during morning warm-up
- Install attic ventilation
- Use window fans
- Redirect air diffuser in non-cooling seasons
- Maintain filters monthly
- Check damper operations monthly
- Check belt tension monthly
- Post and use operational and schedule sheet

Heating System ECOs

- Reduce outside air
- Waste heat utilization
- Tune-up boilers
- Repair and/or replace steam traps
- Repair hot water and steam leaks
- Reduce boiler pressure in response to load
- Fire one boiler at full load rather than two at part load
- Maintain boiler instruments
- Reduce space temperatures to 65°
- Reset space temperature during off hours

Hot Water System ECOs

- Repair leaks
- Reduce water temp. - 105°F (handwashing only), 120°F (showers)
- Install water flow restrictors/flush dams

- Install timers on hot water heaters and circulating pumps
- Insulate hot water tank
- Turn off hot water in summer
- Flush system annually

Illumination System ECOS

- Use higher efficiency fixtures and lamps
- Clean fixture lenses and reflectors
- Remove lights (and disconnect ballasts) where not needed
- Install time-out switches
- Use photocells/timeclocks on exterior lights
- Install multi-level brightness controls
- Use high reflectance paint on interior surfaces
- Install night-lighting system

Electrical System ECOs

- Install electric metering and sub-metering
- Clean or replace contact surfaces on motor starters
- Increase conductor size on large motors
- Use high efficiency motors and transformers for replacement
- Correct low power factor
- Install load warning or load shedding devices
- Keep electric motors in good condition
  (lubricate, replace worn bearings, check alignment, clean, tighten belts and pulleys)

Aeration System ECOs

- Change fuel source (utilize digester gas-driven engine)
- Improve oxygen transfer efficiency
  (change header placement geometry, optimize mixing pattern, retrofit coarse bubble with fine bubble diffusers, increase operating depth)
- Modify blower function
  (variable speed drives, throttling blower suction for hp savings, automatic control based on D.O., adjusting volume based in diurnal/seasonal variations, meet mixing requirements at low loadings)

Sludge Handling System ECOs

- Digester gas utilization
  (electric generation with heat recovery, blower drive, pump drive, boiler fuel)
- Waste heat recovery from incineration

CONCLUSIONS

Based on the information acquired from the study of the energy conservation opportunities available at the various treatment sites, the following conclusions have been identified:

(1) Municipal wastewater systems in Michigan rely almost entirely on electricity and natural gas for their energy requirements. The reliance on each of these two energy sources is roughly equal.

(2) The major components of energy consumption in wastewater systems are electricity for aeration blower drives and natural gas for sludge heating and incineration. Therefore, these areas offer the greatest opportunity for conservation.

(3) The six-step process optimization model presented in this paper can be quite successfully used in identifying energy and chemical conservation opportunities related to treatment processes.

(4) No obvious relationship exists between the size of a wastewater facility and the efficiency with which it consumes energy.

(5) It is projected that municipal wastewater systems in Michigan could reduce their electricity consumption by about 15 percent and their natural gas consumption by about 20 to 25 percent through the implementation of cost-effective energy conservation measures.

(6) Approximately 15 to 20 percent of the total identified energy-saving potential in a wastewater system can be achieved through operational and maintenance changes costing less than $500 and having an average simple payback period of less than one month.

(7) Significant energy conservation opportunities relating to HVAC and illumination systems exist in municipal wastewater facilities because of the unusual occupancy pattern in many areas of the facility.

(8) Municipal wastewater facilities have significant indirect energy impacts as a result of their consumption of large quantities of chemicals produced by energy-intensive manufacturing processes.

REFERENCES

1. An Explanatory Study of Possible Energy Savings as a Result of Water Conservation Practices. NTIS No. PB-260 490. Prepared for the Ofce. Water Res. and Technol., Washington, D.C. (Jul. 1976).

2. In-house rate studies: Ayres, Lewis, Norris & May, Inc., Engineers - Architects -Planners, Ann Arbor, Michigan.

"The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred."

TABLE 1

ENERGY REQUIREMENTS FOR CHEMICAL PRODUCTION

Chemical	Fuel (Btu/ton) x 10^6	Power (kwh/lb)
Activated Carbon	102.0[a]	4.9
Alum	2.0[a]	0.1
Ammonium Hydroxide	41.0[a]	2.0
Carbon Dioxide	2.0	0.1[a]
Chlorine	42.0	2.0[a]
Ferric Chloride	10.0	0.5[a]
Lime (Calcium Oxide)	5.5[a]	0.3
Methanol	36.0[a]	1.7
Oxygen	5.3	0.25[a]
Polymer	3.0	0.1
Salt (Sodium chloride)		
Evaporated	4.0[a]	0.2
Rock and Solar	0.5	0.024[a]
Sodium Hydroxide	37.0	1.8[a]
Sulfur Dioxide	0.5	0.024[a]
Sulfuric Acid	1.5	0.1

Source: "Energy Conservation in Municipal Wastewater Treatment," U.S. EPA., March, 1978.

[a] Indicates principal type of energy used in production. Does not include energy for transportation.

TABLE 2

SITES STUDIED

Study Site	Design ML/d	Capacity mgd	Service Area Population	Type of Treatment[a]	Sludge Handling Facilities[b]
E. Lansing, MI	68	18.0	105,000	$T/AS/PO_4/NH_3$	SD/SI
Big Rapids, MI	9	2.4	16,500	$S/AS/PO_4$	AN
Alma, MI	9	2.5	9,700	$S/AS/PO_4/NH_3$	CSS
Wyoming, MI	72	19.0	59,600	$S/TF/AS/PO_4$	CSS
Cadillac, MI	8	2.0	10,200	$T/AS/RBC/PO_4/NH_3$	AN/SD
Ann Arbor, MI	30	8.0	104,000	$S/AS/PO_4/NH_3$	AN/SD/SI
Saline, MI	7	1.9	6,500	$T/TF/PO_4$	AN/SD
Greenville, MI	5	1.3	8,000	$S/TF/PO_4$	AN/SD

[a] Primary - P
Secondary - S
Tertiary - T
Activated Sludge - AS
Trickling Filter - TF
Rotating Biological Contactor - RBC
Phosphorus Removal - PO_4
Ammonia Removal - NH_3

[b] Anaerobic Digestion - AN
Aerobic Digestion - AE
Sludge Dewatering - SD
Sludge Incineration - SI
Chemical Sludge Stabilization - CSS

TABLE 3
ENERGY CONSUMPTION BY FUEL TYPE AT EACH STUDY SITE
(in percent)

Study Site	Electricity	Natural Gas	Fuel Oil
East Lansing, MI	47	53	0
Big Rapids, MI	46	54	0
Alma, MI	82	18	0
Wyoming, MI	60	40	0
Cadillac, MI	52	48	0
Ann Arbor, MI	25	60	15
Saline, MI	44	56	0
Greenville, MI	81	19	0

TABLE 4
BREAKDOWN OF ENERGY CONSUMPTION BY FUNCTIONAL SUB-SYSTEMS
(in percent)

Study Site	Capacity Control System	Treatment System	HVAC System	Illumination System
East Lansing, MI	10	72	14	4
Big Rapids, MI	5	58	31	6
Alma, MI	9	70	18	3
Wyoming, MI	11	44	41	4
Cadillac, MI	11	49	36	4
Ann Arbor, MI	4	74	14	8
Saline, MI	26	57	15	2
Greenville, MI	26	54	18	2

TABLE 5

ENERGY CONSUMPTION AND ENERGY COST OF WASTEWATER TREATED AT EACH FACILITY

Study Site	Energy Consumption per m^3		Energy Cost	
	$kj/m^3 x 10^3$	$Btu/mil gal x 10^6$	per m^3	per mil gal
East Lansing, MI	6.1	21.9	$0.035	$133
Big Rapids, MI	3.9	14.0	0.026	98
Alma, MI	1.8	6.6	0.017	63
Wyoming, MI	2.6	9.2	0.015	57
Cadillac, MI	4.2	14.9	0.034	131
Ann Arbor, MI	4.7	16.9	0.023	89
Saline, MI	2.2	7.8	0.016	59
Greenville, MI	5.8	20.9	0.028	105

TABLE 6

A MODEL FOR TREATMENT PROCESS OPTIMIZATION

(1) REVIEW OF HISTORICAL RECORDS

- chemicals used/mg
- influent water quality
- effluent water quality (NPDES Permit)
- process performance parameters

(2) PLANT PERFORMANCE VS. EXPECTED DESIGN PERFORMANCE

- theoretical vs. actual performance from (1) above
- establish efficiencies of various unit processes
- establish marginal utility of adding chemicals

(3) REVIEW PARAMETERS AFFECTING THE UNIT PROCESSES

- grit removal
- rapid mixing
- flocculation
- settling
- aeration

(4) REVIEW ALTERNATE APPROACHES FOR ACHIEVING PROCESS RESULTS

- changing chemical feed point
- recirculation of solids
- alternate chemicals
- varying treatment needs (winter vs. summer)

(5) CONDUCT LAB SCALE STUDIES

- run jar tests with different chemicals and chemical dosages
- evaluate results

(6) CONDUCT PLANT SCALE STUDIES

- change one parameter at a time
- evaluate results
- implement plant changes

TABLE 7
LIST OF ENERGY CONSERVATION OPPORTUNITIES
ANN ARBOR WASTEWATER TREATMENT PLANT

Description	Annual Energy Savings[a]	Annual Cost Savings	Implementation Cost	Payback Period (yrs)
Reduce Heat Recovery Unit Capacities	76,800 kwh 2,500 ccf	$ 3,455 1,000	$ 3,000	0.7
Power Factor Correction[b]	---	2,592	4,880	1.9
Digester Gas Utilization[c] (Blower Engine) (Heating)	248,330 kwh 44,896 ccf	11,170 17,958	25,935 --	2.2
Activated Sludge Aeration	486,850 kwh	21,910	62,000	2.8
Lab Exhaust Hood Makeup	2,845 ccf 2,290 kwh	1,138 103	4,500	3.6
Insulate Digester Covers	110,500 kwh	4,972	26,180	5.3
Install (1) Boiler Economizer	5,000 ccf	2,000	20,000	10.0
Insulate Blank Walls	4,550 ccf	1,820	24,600	13.5
Roof Insulation	2,156 kwh 941 ccf	97 376	6,505	13.7
Install (2) Boiler Economizers	6,100 ccf	2,440	25,000	14.3
Replace Overhead Doors	747 ccf	299	4,465	14.9

[a] Base Costs: Electricity = $.045/kwh; Natural Gas = $.40/ccf, where ccf=100 cubic feet

[b] No direct energy savings associated with this ECO.

[c] Digester heating equipment purchased separately.

TABLE 8
LIST OF ENERGY CONSERVATION OPPORTUNITIES
EAST LANSING WASTEWATER TREATMENT PLANT

Energy Conservation Opportunities	Projected Annual Energy & Cost Savings: Electricity Amount (kwhr)	Electricity Cost ($)	Natural Gas Amount (cu ft)	Natural Gas Cost ($)	Total Amount (Btu x 10^6)	Total Cost ($)	Implementation Cost ($)	Simple Payback Period (years)
Installation of More Efficient Variable-Speed Drives	55,500	1,780	--	--	189.4	1,780	27,000	15.2
Preferential Operation of Most Efficient Raw Sewage Pumps	6,000	200	--	--	20.5	200	-0-	-0-
Monitoring of Pump Efficiency[1]	--	--	--	--	--	--	--	--
Reduction of Fuel Requirements for Sludge Incineration	--	--	29,200,000	87,600	29,200	87,600	1,200,000	13.7
Recovery of Incinerator Exhaust Heat[2]		--	--	--	--	--	--	--
Bypassing of Tertiary Filters[3]	--	--	--	--	--	--	--	--
Modification of Aeration System	396,000	12,700			1,351.5	12,700	70,800	5.6
Lowering of Water Level in Equalization Basin	641,600	20,500	--	--	2,189.8	20,500	-0-	-0-
Cleaning of Boiler	--	--	1,450,000	4,350	1,450	4,350	800	0.18
Reduction of HV-2 Use	25,200	810	473,000	1,420	559	2,230	-0-	-0-
Reduction of Outside Air	--	--	4,527,000	13,580	4,527	13,580	7,700	0.57
Recovery of Waste Heat from Aeration Blowers	--	--	148,000	440	148	440	-0-	-0-
Installation of Water Source Heat Pumps[4]	--	--	--	--	2,971.6	300	75,000	250
Installation of Insulated Glass	--	--	91,200	273	91.2	273	11,195	41
Recovery of Waste Heat from Transformers	116,000	3,713	--	--	395.9	3,713	37,000	10
Increase in Conductor Size[3]	--	--	--	--	--	--	--	--
Correction of Motor Circuit Power Factor[5]	—	—	-	—	—	—	—	—
Replacement of Standard Fluorescent Fixtures with Low-Wattage Fluorescent Fixtures	40,200	1,290	--	--	137.2	1,290	3,240	2.5
Replacement of Incandescent Lamps with Self-Ballasted Metal Halide Fixtures	97,900	3,130	--	--	334.1	3,130	3,370	1.1
Replacement of Mercury Vapor Fixtures with High-Pressure Sodium Fixtures	48,500	1,550	--	--	165.5	1,550	2,520	1.6
Replacement of Manual Switches with Time-Out Switches	108,500	3,470	--	--	370.3	3,470	1,760	0.5
TOTALS	1,535,400	49,143	35,889,200	107,663	44,101	157,106	1,440,385	

[1] This ECO is unquantifiable within the scope of this study so no values are given for costs or savings.

[2] The energy savings associated with this ECO are estimated in Section 2.2.4. It was beyond the scope of this study to estimate the implementation costs, therefore, all values for this ECO were omitted rather than inflate the total energy savings for all ECOs relative to implementation costs.

[3] Annual totals cannot be estimated for this ECO because it applies to only certain periods of the year. Weekly savings estimates are given in Section 2.2.4.

[4] Because this ECO involves changing from one heating source to another, only the total savings in Btu was given.

[5] The energy which could be saved through this ECO and the cost to implement the ECO are both dependent on the extent of implementation, therefore these estimates were not included.

TABLE 9

LIST OF ENERGY CONSERVATION OPPORTUNITIES
BIG RAPIDS WASTEWATER TREATMENT PLANT

	Projected Annual Energy & Cost Savings							
	Electricity		Natural Gas		Total			
Energy Conservation Opportunities	Amount (kwhr)	Cost ($)	Amount (cu ft)	Cost ($)	Amount (Btu x 10^6)	Cost ($)	Implementation Cost ($)	Simple Payback Period (years)
Reduction of Lift Pump Speed	4,000	160	--	--	13.6	160	100	0.625
Reduction of Blower Operation	30,700	1,228	--	--	104.8	1,228	-0-	-0-
Use of Fine Bubble Aeration Diffusers	111,300	4,500	--	--	379.8	4,500	10,000	2.22
Increased Use of Digester Gas	--	--	600,000	1,800	600	1,800	-0-	-0-
Solar Heating of Digesters	--	--	1,845,000	5,535	1,845	5,535	150,000	27.1
Reduction of Sludge Trucking[1]	--	--	--	--	130.5	1,175	-0-	-0-
Modification of Final Effluent Supply Pumping	154,000	6,160	--	--	525.6	6,160	2,670	0.43
Cleaning of Boiler	—	--	42,000	126	42	126	600	4.8
Installation of Nighttime Setback Controls	--	--	370,000	1,110	370	1,110	5,000	4.5
Reduction of Temperature in Storage Room	--	--	136,000	410	136	410	200	0.49
Modification of Gravity Turbines	--	--	93,500	280	93.5	280	320	1.14
Reduction of Outside Air	--	--	704,000	2,120	704	2,120	4,600	2.2
Use of Waste Digester Gas	--	--	270,000	810	270	810	9,000	11.1
Weatherstripping of Double-Door Astragals	--	--	18,500	55	18.5	55	70	1.3
Enclosure of Existing Main Entrance	--	--	6,600	20	6.6	20	1,020	51
Recovery of Waste Heat from Transformers	12,300	492	--	--	41.9	492	4,920	10
Increase in Conductor Size[2]	--	--	--	--	--	--	--	--
Replacement of Incandescent Fixtures with Low-Wattage Fluorescent Fixtures	40,200	1,610	--	--	137.2	1,610	2,940	1.8
Replacement of Incandescent Lamps with Self-Ballasted Metal Halide Fixtures	48,127	1,930	--	--	164.3	1,930	490	0.25
Replacement of Mercury Vapor Fixtures with High-Pressure Sodium Fixtures	6,131	245	--	--	20.9	245	770	3.1
Replacement of Manual Switches with Time-Out Switches	20,150	800	--	--	68.8	800	280	0.35
TOTALS	426,908	17,075	4,085,600	12,266	5,673	26,066	192,980	

[1] The energy saving associated with this ECO is 1022 gallons of gasoline, worth $1,175 assuming a cost of $1.15/gal.

[2] The energy which could be saved through this ECO and the cost to implement the ECO are both dependent on the extent of implementation, therefore these estimates were not included.

TABLE 10

LIST OF ENERGY CONSERVATION OPPORTUNITIES SALINE WASTEWATER TREATMENT PLANT

Description	Annual Energy Savings	Annual Cost Savings[a]	Implementation Cost[a]	Payback Period (yrs)
Destratifier Fans	195 ccf	$ 22	$ 240	10.9
Digester Gas Utilization	12,180 ccf	4,139	7,300	1.7
Replace Electric Unit Heaters	706 kwh	240	600	2.5
Timer Light Switches	795 kwh	40	120	3.0
Outside Lighting Lamps	1,446 kwh	72	339	4.7
Incandescent Replacement	6,495 kwh	325	2,030	6.2
Lower Wattage Lamps	844 kwh	42	194	3.5
Insulate Digester Roof	4,060 ccf	1,421	1,800	1.3
Insulate Bldg Roofs	590 ccf	206	3,050	14.8
Storm Windows	78 ccf	27	250	9.3
Variable Frequency Drive	70,000 kwh	3,500	12,800	3.7

[a] Based on $.05/kwh and $.35/ccf

ccf = 100 cu ft natural gas

kwh = kilowatt hours electricity

FIGURE 1
SUMMARY OF OPERATING DATA
WASTE WATER TREATMENT PLANT, CADILLAC, MICHIGAN [MARCH 76 - SEPT. 78]

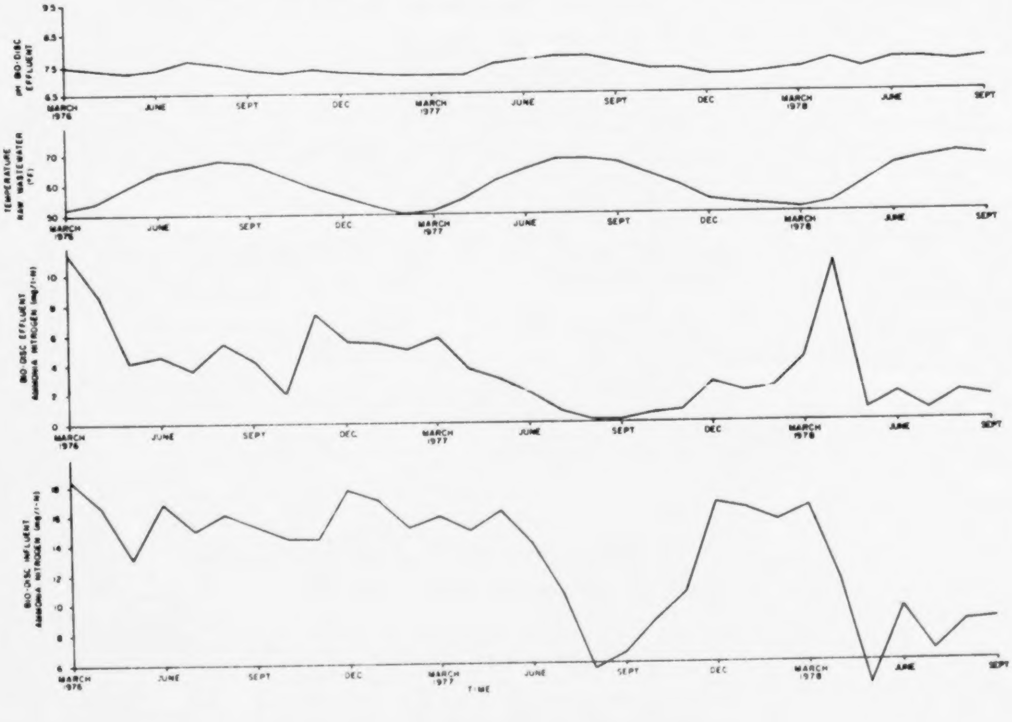
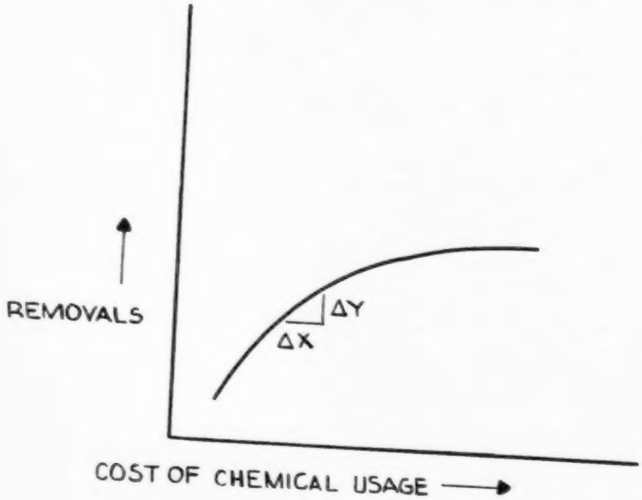


FIGURE 2

MARGINAL UTILITY OF CHEMICAL ADDITION



$$\text{MARGINAL UTILITY} = \frac{\text{INCREMENTAL REMOVAL} \quad (\Delta Y)}{\text{INCREMENTAL COST OF CHEMICAL } (\Delta X)}$$

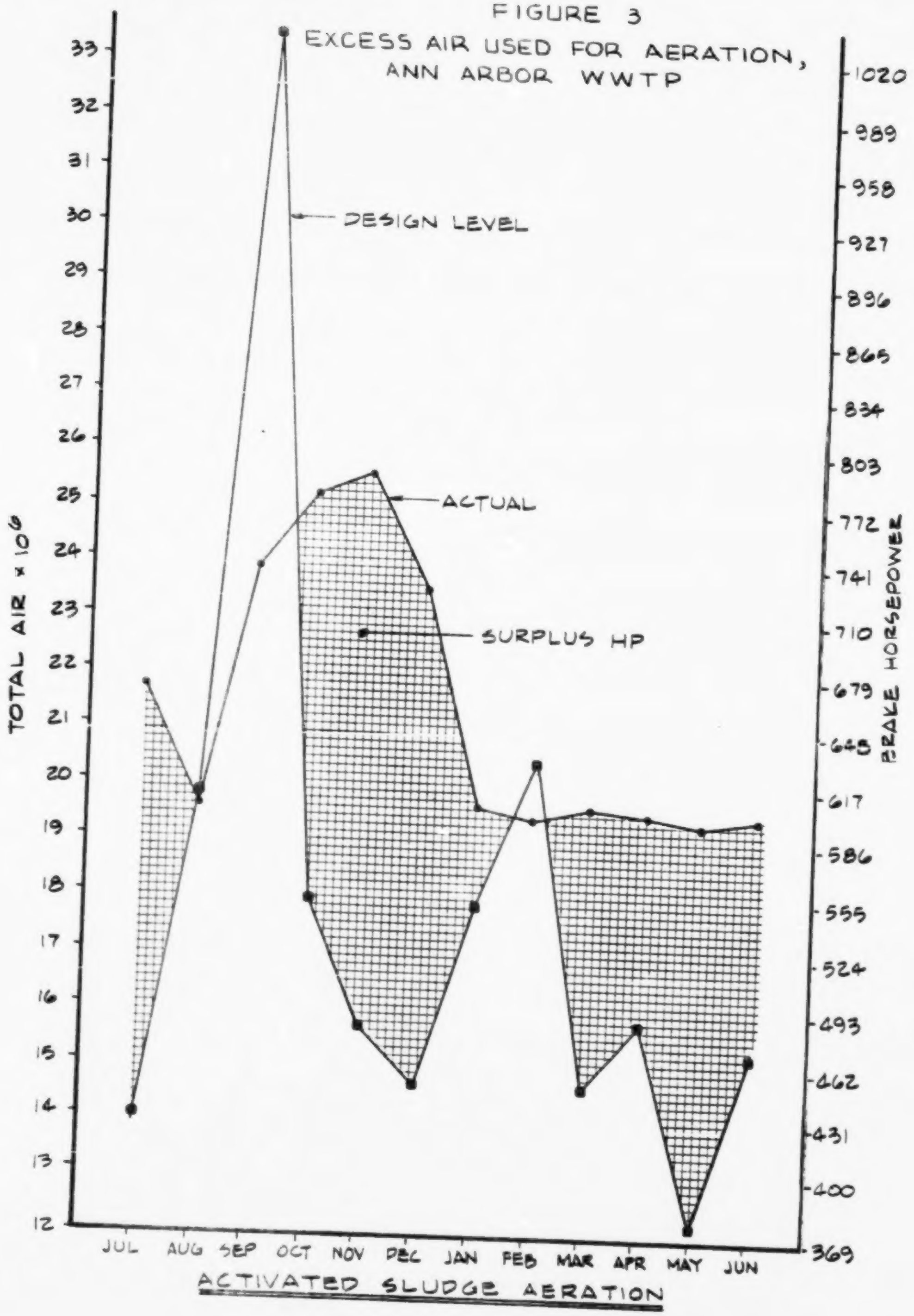


FIGURE 3
EXCESS AIR USED FOR AERATION, ANN ARBOR WWTP

PAPER NO. 17

ALTERNATIVE ENERGY SOURCES IN MUNICIPAL WASTEWATER TREATMENT: THE WILTON, MAINE EXPERIENCE

by

David R. Fuller
Director of Technical Services

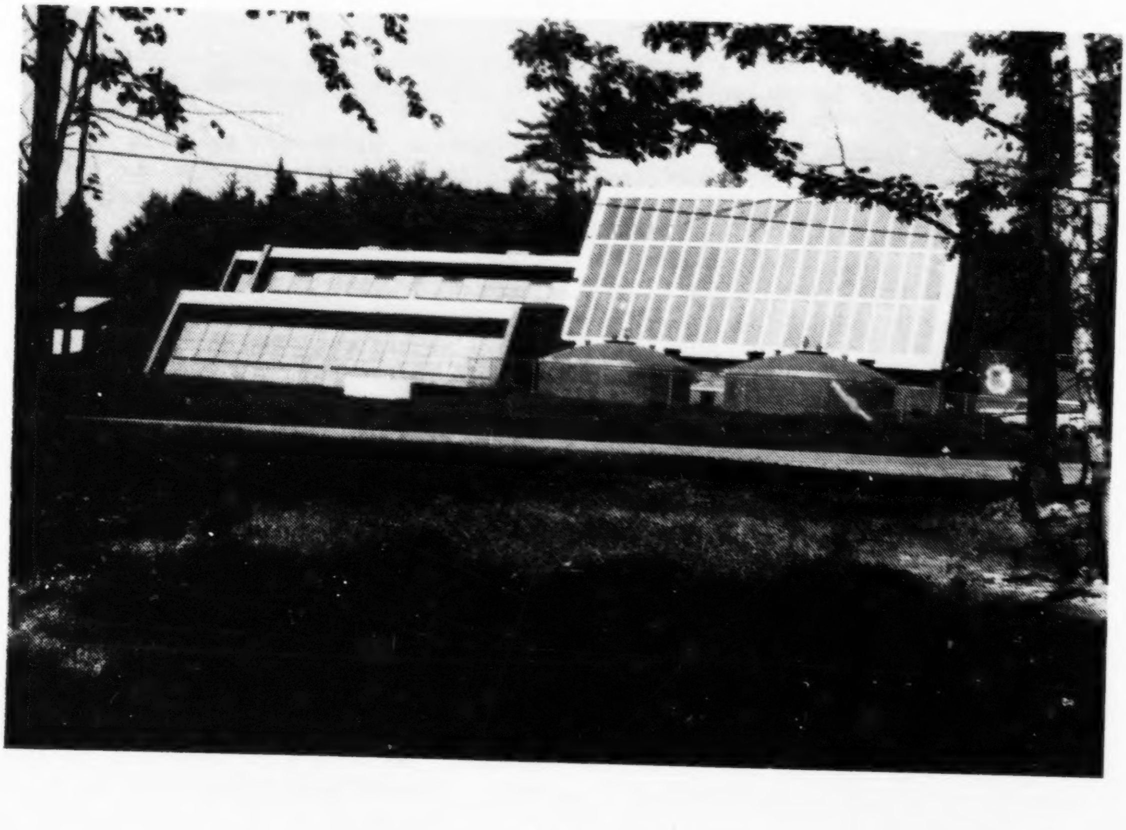
Wright - Pierce Architects and Engineers
Topsham, Maine 04086

ALTERNATIVE ENERGY SOURCES IN MUNICIPAL WASTEWATER TREATMENT: THE WILTON, MAINE EXPERIENCE

David R. Fuller, Director of Technical Services
Wright-Pierce Architects and Engineers

INTRODUCTION

The Municipal Wastewater Treatment Plant at Wilton, Maine was designed to incorporate energy conservation and alternative energy features such as active and passive solar space and process heating, effluent heat recovery, digester gas generation and utilization, ventilation air heat recovery, and electricity generation using digester gas. Designed in 1975 by Wright-Pierce Architects and Engineers of Topsham, Maine and Douglas A. Wilke, Architect and Solar Consultant of Glen Head, New York, the plant became operational in September, 1978. Wright-Pierce received a grant from the U.S. Environmental Protection Agency to monitor the plant's energy systems from May, 1979 to March, 1981. This paper discusses the design of the Wilton facility; the results of the monitoring program; and recommendations for design improvement, with emphasis on the solar heating systems.



DESCRIPTION OF TREATMENT PLANT

The Wilton Wastewater Treatment Plant was designed to provide secondary treatment of the wastewater generated by the Town's population of 4,200, with the added requirement that there be zero discharge to the receiving stream at streamflows less than 0.12 m^3/d the seven-day, ten-year draught flow (7/Q/10).

Figure 1 is a process flow diagram. Wastewater is lifted into the plant by screw pumps. Preliminary treatment consists of grit removal, comminution, flow measuring, sampling, and screening. Secondary biological treatment consists of rotating biological contactors (RBC). Final clarification takes place in two peripheral feed clarifiers. The effluent is then disinfected and discharged.

To meet the 7/Q/10 streamflow limitations, a 4.5 ha spray irrigation plot directly north of the treatment facility is utilized. This system is designed for 10 continuous days' operation during drought conditions.

Sludge, consisting of screenings from the preliminary screens and sludge from the final clarifiers, is combined and mixed in a raw sludge holding tank, then pumped to anaerobic sludge digesters for stabilization. High-rate two-stage mesophilic digestion is used. Following digestion the sludge is pumped to the dewatering area, then conveyed to the disposal vehicle and trucked to a local farm for spreading on fields.

Architecture is a key element in any project where energy conservation and the use of alternative energy sources are prime objectives.

Due to Wilton's cold climate, the entire plant is enclosed in two structures with all the processes placed close together to keep the structures as small as practicable and reduce hydraulic runs, while providing for future expansion. Gravity is used to avoid unnecessary pumping.

The building is shaped to hold snow on the roof and collect drifts of snow against walls for increased natural insulation during the colder months. Projections past the wall lines adjacent to glazed surfaces reduce surface wind velocity and cut heat loss, as do recessed windows and doors.

Basic concrete materials were chosen for walls and roofs, because of heat retention potential and low maintenance factors. Insulated glass is used in all windows.

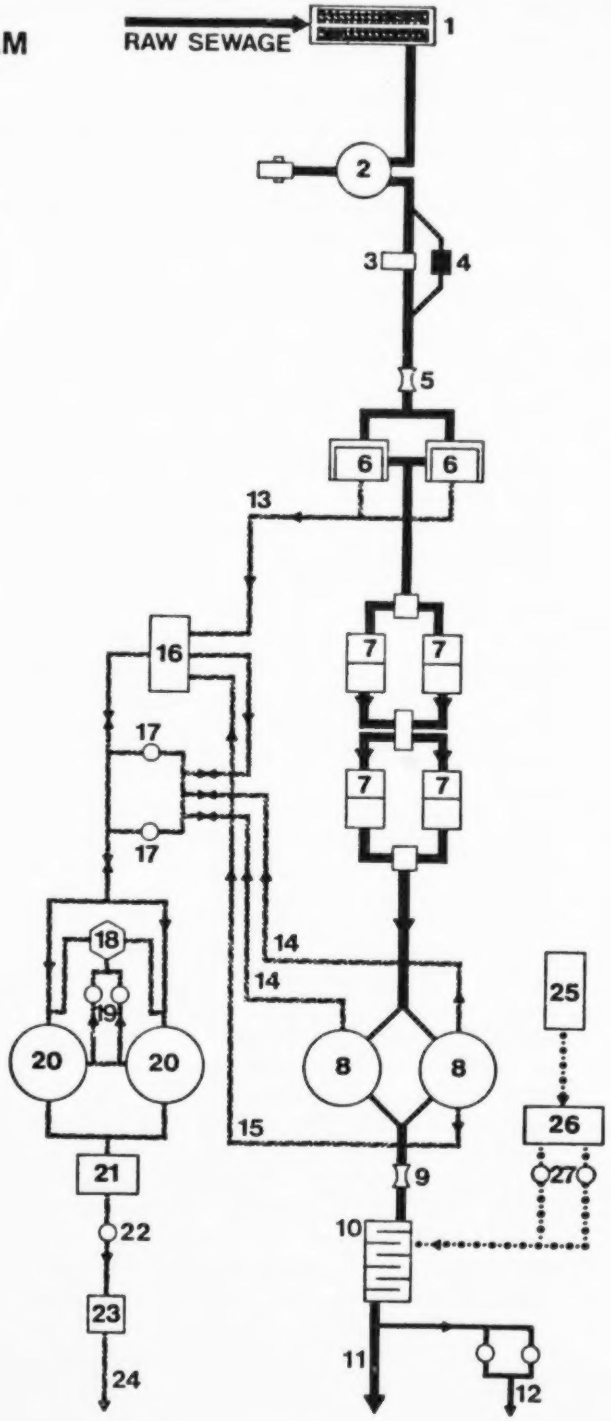
The building interior spaces are partitioned to separate areas requiring different temperatures and different air changes for maximum control of heat loss. Partitions and doors between spaces with a temperature differential of more than 6°C are insulated. Wherever possible, translucent fiberglass partitions are used so lighting from adjacent spaces can be shared . Natural ventilation and air flow is controlled by louvers and windows.

The building is built into a hillside, with little exposure to the north, to minimize the exterior surface. Shrubs and trees provide wind

FIGURE 1

TREATMENT PROCESS DIAGRAM

1 SCREW PUMPS
2 GRIT CHAMBER
3 COMMINUTOR
4 BAR SCREEN BY-PASS
5 FLOW MEASURING & SAMPLING
6 PRIMARY SCREENS
7 ROTATING BIO-CONTACTORS
8 SECONDARY CLARIFIERS
9 FLOW MEASURING & SAMPLING
10 CHLORINE CONTACT CHAMBER
11 PLANT EFFLUENT
12 SPRAY IRRIGATION
13 PRIMARY SLUDGE
14 SECONDARY SLUDGE
15 SECONDARY SKIMMINGS
16 SLUDGE HOLDING
17 SLUDGE TRANSFER
18 SLUDGE HEATER
19 SLUDGE RECYCLE PUMPS
20 ANAEROBIC SLUDGE DIGESTERS
21 SLUDGE HOLDING
22 SLUDGE DEWATERING PUMP
23 DEWATERING UNIT
24 DEWATERED SLUDGE
25 HYPOCHLORITE GENERATION
26 HYPOCHLORITE STORAGE
27 METERING PUMPS



DESIGN CRITERIA

Quantity of sewage
0.02 m^3/s

Influent BOD
200 mg/l (340 kg/d)

Influent suspended solids
200 mg/l (340 kg/d)

Effluent BOD
20 mg/l (34 kg/d): 90% removal

Effluent suspended solids
20 mg/l (34 kg/d): 90% removal

Sludge quantity to digesters
9.5 m^3/d at 3.5% solids

Methane yield
110 to 125 m^3/d

Methane heat value
22,400 kJ/m^3 or 2.4 to 2.7 GJ/d

breaks. Reflection off snow in front of the building and on an earth mound to the west supplements solar energy collection. The enclosing structures are oriented southward to achieve maximum value from the sun's direct energy through both passive and hydronic solar energy collection devices.

Insulated translucent fiberglass panels are oriented to the south at a 60 degree tilt for passive collection of solar energy. The panels cover 89 m^2, have a light transmission factor of 45% and a 0.29 "U" factor.

Flat plate hydronic solar collector panels covering 130 m^2 set at a 60 degree slope form the south roof of the treatment plant. The collector consists of an extruded aluminum plate and frame, copper tubing to transport the collector fluid, and two panes of low iron content tempered glass. The backs of the collectors are insulated with 114 mm of rigid polyisocyanurate foam board insulation. An ethylene glycol solution is pumped through these panels and heated to 50°- 60°C by the sun.

Although solar energy is used for space heating and domestic hot water, its primary purpose is to provide heat for the anaerobic digesters. The methane gas produced in the digestion process can be stored and used not only in the methane boiler for heating purposes, but to run the plant's emergency generator. This application of solar energy attempts to overcome two of the main constraints on its widespread acceptability, namely its traditional seasonal use and the difficulty of storing solar energy. By using solar to heat the digesters, the solar equipment is used year round, significantly decreasing the pay-back period. By producing methane as part of the anaerobic sludge digestion process, solar energy is effectively stored in the form of a compressible, combustible gas, a much more efficient storage medium than the usual hot air or water.

A sophisticated heating and ventilating design had to be achieved in order to accomplish the energy goals. Because the main component is solar energy using flat plate collectors in a cold climate, a basic constraint on the heating system design was the use of relatively low temperature hot water (50°C.) instead of the conventional 90°C water. Energy conservation practices become extremely important when dealing with such low temperatures. The thermal zoning of rooms to allow for individual room temperature control is very important. The office, locker room and laboratory which are clustered at the northeast end of the building can be maintained at 20°C for the operator's comfort. The rest of the areas in the plant will experience seasonal and diurnal temperature fluctuations, dropping to as cold as 7°C in winter and perhaps approaching 30°C on warm, sunny days in the summer. The operators are normally not in these areas for any extended period of time. It also should be kept in mind that most of these areas contain processes which normally are not housed. The operator is very important to the success of the energy conservation effort, in that he must see to it that temperature controls are properly set, the doors are kept closed and that temperatures are set back at night.

The heating system is designed for cascading the heating loads. The digesters can be heated with 49°C water, building space heating can be accomplished with 38°C water and ventilation units use 32°C water. The water which heats the digesters can, in turn, be used to supply heat to the building's heating system and ventilation units without requiring supplemental heat between steps. The system maintains the flexibility of supplying heat directly to one specific load as required.

Ventilation is a major problem in energy efficient heating design for wastewater treatment plants, in that many of the process areas require many air changes. In order to avoid throwing heat away, the plant makeup air is conditioned with the exhaust air before it is vented.

Solar energy is the prime source of heat, both for the sludge digestion process and the building. A secondary source of heat is the methane gas produced in the anaerobic digesters, and its availability is intimately dependent upon the success of solar heating. Another source of heat is an electric heat pump which utilizes the heat energy available in the plant's effluent. This heat pump is approximately three times as efficient as electric resistance heat, and its use in wastewater treatment facilities can be very cost-effective.

Figure 2 represents the inter-relationships among the heating sources and heating loads. Heat from the solar collectors can either be transmitted directly to the heat distribution system or can be sent to the solar energy storage tank, which is a 7.5 m^3 water tank. Which route it takes depends on the relative temperatures of the solar collector loop and the solar storage tank and on the needs of the system for heat.

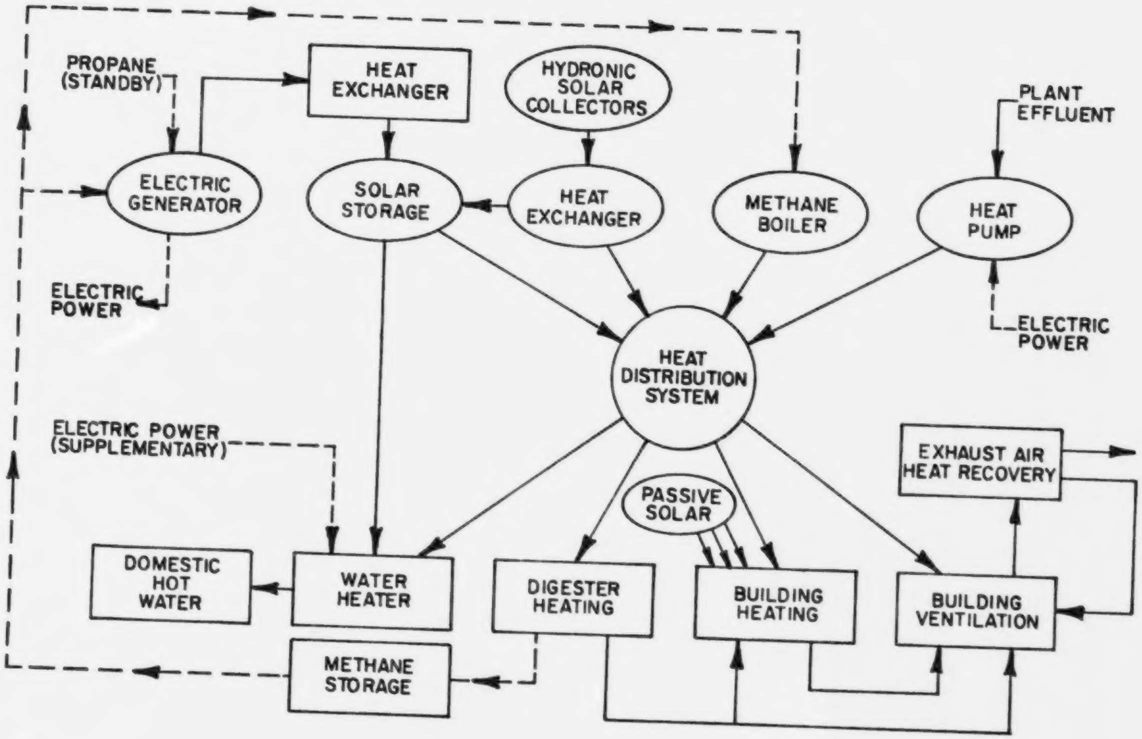
Fueled by digester gas produced in the anaerobic digesters, the methane boiler comes on only when there is a call for heat that cannot be satisified either by direct input of solar energy or by hot water stored in the solar storage tank. The heat pump operates only when solar is unavailable either directly or indirectly and methane is unavailable.

Backing up the three primary heat sources are some secondary sources which can be significant. Methane is used as the prime fuel for the plant's 55 KW electric generator in addition to fueling the methane boiler. Propane is stored on site in case of prolonged power outages when the supply of methane is exhausted, but is not normally used as a fuel for the generator. When the generator is operating it gives off a great deal of heat. It is cooled by water from the solar storage tank, thus becoming a usable source of heat.

The solar storage tank can be considered a heat source. It is used for short-term storage of excess energy which is not directly usable. By utilizing the storage capacity, the operator does not waste potentially usable energy from the solar collectors or the electric generator. Heat from the solar storage tank can either be put into the heat distribution system or go directly to heating domestic hot water. The hot water heater can be heated electrically, but it is unlikely that this will often be required.

FIGURE 2

ENERGY SYSTEMS CONCEPTUAL DIAGRAM


PROPANE (STANDBY)
HEAT EXCHANGER
HYDRONIC SOLAR COLLECTORS
PLANT EFFLUENT
ELECTRIC GENERATOR
SOLAR STORAGE
HEAT EXCHANGER
METHANE BOILER
HEAT PUMP
ELECTRIC POWER
ELECTRIC POWER
HEAT DISTRIBUTION SYSTEM
ELECTRIC POWER (SUPPLEMENTARY)
EXHAUST AIR HEAT RECOVERY
PASSIVE SOLAR
DOMESTIC HOT WATER
WATER HEATER
DIGESTER HEATING
BUILDING HEATING
BUILDING VENTILATION
METHANE STORAGE

Passive solar energy is provided by translucent fiberglass panels for direct heating and lighting. Finally, building ventilation air is conditioned by exhaust air through the use of a heat exchanger.

To accomplish the objectives of the digester gas system, two levels of storage are used. Short duration storage is accomplished by compressing the gas to 138 KN/m^2. This is a conditioning storage mode used to insure steady flow of methane for digester mixing and to prevent too rapid cycling of the high pressure methane storage compressor. Longer duration storage is accomplished through the high pressure methane storage system, in which methane is compressed to 1,380 KN/m^2. It is from the high pressure gas storage tank that the boiler and generator are supplied.

ENERGY MONITORING OBJECTIVES AND DESCRIPTION

The objectives of the energy systems monitoring program were to predict, verify, and summarize the performance of the building thermal systems on a totally integrated basis that is not available through predictive analysis of individual components.

These objectives are tied very closely to the basic energy conserving design of the plant. Each subsystem is not especially unique in design by itself; however, the integrated subsystems pose complex problems in the interaction of process variables. This is especially prevalent in interaction between energy sources, i.e. solar input, methane boiler, heat pump; and energy users, i.e. digesters, building heating and ventilation.

The integration of these subsystems is unique; and the design was based, in part, on data provided by solar, emergency generator, boiler and digester manufacturers who have detailed knowledge of their equipment but limited knowledge of the total system. It is in these areas that the system was monitored to determine how the components interface.

Active Solar

In the active solar subsystem an ethylene glycol water solution is circulated through collector plates which are heated from the sun's rays. This energy is then exchanged to the plant circulating water system. An underlying design premise is to use solar energy whenever it is available, with the use as a function of exchanged temperature. The total performance of this subsystem needed to be determined.

Solar insolation was measured (for (1) direct, diffuse and reflected and (2) direct and diffuse only) and continuously recorded on a strip chart with an integrated digital output as well. Solar plate temperature and glycol flows and temperatures were also recorded. A hydronic BTU computer monitored the total heat from the solar heat exchanger for both analog and digital recording. Electrical input to solar pumps was also monitored.

Digester

The digester subsystem again is not especially unique in its function and design; however, the integration with the total system and its part in the energy conserving nature of the plant is unique. The digester gas released becomes an important part of the total operation, as it was designed to be used in the gas boiler in normal operation and the emergency generator when excess gas is available.

A determination was made to the quality and quantity of gas produced and where it is used. The properties and quantities of the sludge flow in and out of the digester, the sludge and digester temperatures and the heating and electrical requirements were monitored.

Effluent Heat Pump

The heat pump extracts heat from the effluent for use in the heated water system.

Electrical input and heating output were monitored continuously with digital outputs. Additionally, temperature and pressure drops across the evaporator and condenser and the auxiliary pump electrical usage were monitored. The unit coefficient of performance was determined for various conditions.

Passive Solar

Light/heat transmitting panels are employed in this plant. Their contribution to the total plant energy provides useful design data for scaled-up plants.

Solar insolation and solar transmissivity were measured and continuously recorded. Space temperature and heating requirements were also monitored to give an indication of the heat storage effect of the structural mass of the building.

Weather Data

All design calculations for this plant were based on weather data provided by the National Weather Bureau. Environmental conditions were monitored using a small weather station located at the Wilton treatment plant. The data can be used as a correlation for actual plant performance especially in solar input as a function of ambient temperature, wind velocity, season, etc.

Electrical/Fuel Consumption

This plant's equipment was designed for high efficiency, high power factor and low energy consumption. High pressure sodium lighting was employed where possible with selective switching and task lighting. Equipment was arranged for selective running from the emergency generator depending on gas production.

All significant electrical usage was monitored and audited by function so the total energy requirements for systems such as solar can be determined.

Digester gas production and propane usage were recorded.

Ventilation Air Heat Recovery

An air-to-air heat exchanger is used to recover heat from plant exhausts. The efficiencies for varying conditions were determined and the increased fan power pressure drops were recorded.

Domestic Hot Water System (DHW)

The DHW system is designed to recover heat from either the storage tank or the system return water whenever possible. A hydronic BTU computer monitored its output along with the electrical input. System losses and the recovery pump requirements were determined.

Process Flow

Temperatures were recorded at various points to determine the heat transfer between the process flow and the plant.

RESULTS

The monitoring system was designed and installed based on anticipated results. Generally, the equipment was of sufficient sensitivity and range to provide valid results. With the available data, each major component of the heating system was analyzed and evaluated for its energy and cost-effectiveness.

From Table 1 it can be seen that each of the energy subsystems, except for Digester Gas Production, was a net energy producer and net cost saver. However, the pay-back periods generally were greater than are economically justifiable.

TABLE 1

ENERGY AND COST-EFFECTIVENESS SUMMARY

Component	Energy Output/ Input Ratio (1)	Value Output/ Input Ratio (2)	Cost-Effective
Active Solar	11.5	3.5	No
Passive Solar	32% (3)	N/A	No
Heat Pump	2.9	1.5	Yes
Generator Heat Recovery	113	86	No (4)
Air-to-Air Heat Exchanger	9.0	6.1	Yes
Digester Gas Production	0.59	0.72	No

[1] The Energy ratio is the total energy produced divided by the energy input required.

[2] The Value Ratio is the dollar value of the energy produced divided by input energy cost.

[3] Actual average monthly solar radiation transmitted through panels from June 1, 1979 to April 1, 1980.

[4] Due to low usage; if used more, it could be cost-effective.

Active Solar

Table 2 summarizes the active solar system data between June, 1979 and April, 1980, as follows:

1. Recorded clear day insolation levels were consistently above ASHRAE estimates with an average difference of 13.8% (Item 9).
2. The recorded percent of possible sunshine was 60% versus an average of 52% predicted (Item 5). This is consistent with the unusually low precipitation levels experienced.
3. The average incident solar radiation was 37.3% above that estimated (Item 11).
4. The total solar energy collected was 122 GJ (Item 16) which was 64% of that estimated.
5. The overall solar system efficiency, being the net energy collected divided by the total incident available, was 23% (Item 15).

An overall efficiency of 23% is significantly lower than that anticipated. A great deal of effort was spent in investigating the reasons which were presumed to be one or more of the following:

1. Data/Instrumentation error.
2. Collector Heat Loss Factor
    a. Inadequate thermal isolation.
    b. Possible convective losses between the absorber plate and the rigid insulation.
3. Collector Heat Transfer Losses
    a. Air within the fluid loop.
    b. Effect of the glycol solution.
4. Control sequencing and response.
5. Collector response sensivity.
6. Collector efficiency losses due to dirt accumulated during construction.

While all of these factors (excluding the first) certainly contribute to the solar system performance, the overriding cause appears to be the combination of all of them coupled with and the lack of an accurate calculation procedure to simulate this interaction.

There is obviously a significant difference between instantaneous collector efficiency and day-long or, more importantly, year-long collector efficiency. Instantaneous efficiencies are useful in comparing various

Table 2

MONTHLY SUMMARY AND SOLAR UTILIZATION

1	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	See Note
2	Days in Month	31	29	31	30	31	30	31	31	30	31	30	31	
3	ASHRAE Clear Day Insolation (W/m²) (A)	229	276	286	267	248	238	243	259	272	260	225	205	A
4	Grumman Clear Day Insolation (W/m²) (B)	217	263	273	257	234	220	222	239	257	260	232	199	B
5	Mean Percent of Possible Sunshine (C)	43	51	53	53	57	62	63	61	58	54	39	38	C
6	Probable Available (4 x 5)	93	134	145	136	133	136	140	146	149	140	90	76	
7	Recorded Average Insolation (W/m² Day)	149	198	172	--	--	191	198	172	228	123	112	137	
8	Recorded Clear Day Insolation (W/m² Day) (D)	277	300	338	--	--	264	237	309	304	301	262	245	D
9	Recorded I/ASHRAE I (8 / 3) (E)	1.21	1.09	1.18	--	--	1.11	0.97	1.19	1.12	1.16	1.16	1.19	E
10	Recorded Clearness (7 / 8) (N)	0.54	0.66	0.51	--	--	0.72	0.84	0.56	0.75	0.41	0.43	0.56	N
11	Recorded I/Probable I (7 / 6) (F)	1.60	1.48	1.19	--	--	1.40	1.42	1.18	1.53	0.88	1.24	1.81	F
12	Probable Net Collected (W/m² Day) (G)	41	63	71	65	61	62	69	78	83	77	46	33	G
13	Actual Net Collected (W/m² Day) (H)	23	44	44	--	--	33	28	402	79	33	27	35	H
14	Net Collected/Probable Net (13 / 12)(I)	0.56	0.71	0.62	--	--	0.54	0.41	0.54	0.95	0.43	0.58	1.08	I
15	Net Collected/Recorded I (13 / 7 x 100)(J)	15.5	22.4	25.4	--	--	17.4	14.1	24.5	34.5	27.2	23.6	25.9	J
16	Total Solar Produced (GJ) (K)	7.45	13.25	14.06	--	--	10.31	8.93	12.90	13.16	10.67	8.22	11.33	K
17	Total Heating Load (GJ) (L)	101.63	92.16	91.54	--	--	16.96	9.99	17.16	29.33	46.58	47.24	87.44	L
18	Percent Solar (16 / 17 x 100) (M)	7	14	15	--	--	61	89	75	88	23	17	13	M
19	Average Daily Temperature (°C)	-7	-8	-1	5	11	17	22	17	12	8	4	-4	

A. Solar insolation for the 21st of each month, 44° latitude, 59° tilt from the horizontal, facing due south.

B. Solar insolation for the 15th of each month, 44° latitude, 60° tilt from the horizontal facing 2° west of south. Data used in original projections.

C. Tabulation derived from "Normals, Means, and Extremes" table in U.S. Weather Bureau publication, Local Climatological Data. 53 percent average using Albany, New York.

D. Actual clear day data recorded for each month.

E. 13.8 percent over ASHRAE clear day data.

F. 37.3 percent over probable available insolation.

G. Probable net collected 6x collector efficiency factors.

H. Net collected (water side of solar heat exchanger).

I. 64.2 percent of that estimated.

J. 23 percent of recorded incident solar collected.

K. For 119.5 m² collector surface, 122.9GJ/10 months.

L. Heating load includes process, transmission and ventilation loads.

M. 23 percent overall being supplied by solar.

N. Actual average percent of possible sunshine - 60 percent.

types of collectors under similar steady state conditions, but tend to create a misleading picture of the efficiency of water heating systems operating over long periods.

In the month of March, for example, approximately 1/3 of the incident radiation was of too low an intensity to collect. In many cases the collector plate temperature never reached a usable or threshold level although considerable insolation was available. An illustration of these losses in long term efficiency is shown in Figure 3 for a clear day. The corresponding losses for a cloudy day are obviously greater, particularly if the solar radiation intensity equals the critical, or threshold intensity.

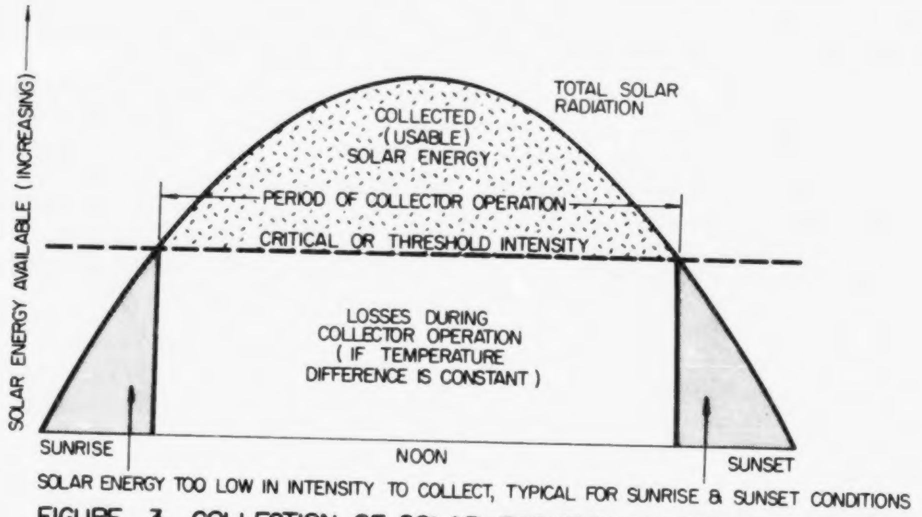

SOLAR ENERGY AVAILABLE (INCREASING)
TOTAL SOLAR RADIATION
COLLECTED (USABLE) SOLAR ENERGY
PERIOD OF COLLECTOR OPERATION
CRITICAL OR THRESHOLD INTENSITY
LOSSES DURING COLLECTOR OPERATION (IF TEMPERATURE DIFFERENCE IS CONSTANT)
SUNRISE
NOON
SUNSET
SOLAR ENERGY TOO LOW IN INTENSITY TO COLLECT, TYPICAL FOR SUNRISE & SUNSET CONDITIONS

FIGURE 3 COLLECTION OF SOLAR RADIATION THROUGHOUT THE DAY

The dominant factor in establishing the threshold intensity level is the temperature difference between the absorber plate and the ambient air. If this difference is minimized by either a warmer climate or a cooler collector fluid, as in the case of a heat pump assisted system, or both; then this threshold level would be reduced and the long term system efficiency improved. For example, in the case of a heat pump/solar system with an average collector fluid temperature of 10°C and an ambient temperature of 24°C, the threshold intensity level would actually be negative, enabling the system to collect heat without solar radiation.

As indicated, the causes were investigated for the lower overall efficiency based on the assumption that the estimating procedures were accurate. Numerous alternative procedures were studied with similar inflated results. In the course of the investigation several publications were discovered which included test data for actual solar systems monitored for a one year period. The results of these studies are similar to the findings to date at the Wilton plant. Each of the systems monitored consisted of flat plate collectors, non-selective coating, with two glass covers. The first involved a 50 m² solar system located in Morton Grove, Illinois (1). This system was monitored in 1975 by the Fluid Handling Division of ITT and had an overall efficiency of 21%. The second system was located in Fort Collins, Colorado (2). It was monitored for one year by the Solar Energy Applications Laboratory at Colorado State University and had an overall efficiency of 19%.

Passive Solar

The passive solar array is built into the wall at two levels. Solar radiation passes through the array providing both heating and lighting in the Clarifier Room. Each bank of panels has an overhang which tends to shade them during the summer months when heating is not required. Operable windows cool the space when the temperatures become excessive. The energy collected during these times is lost and, therefore, not considered useful.

Increasing the transmissivity and/or decreasing the "U" factor would increase the net quantity of collected solar radiation. More would be provided as useful during the winter but more would have to be dumped during the summer. For the panels, varying the ratio of transmissivity/"U" factor and estimating the net energy collected would provide an indication of what a change in that ratio would do to the system. Other factors such as overhangs, the blocking effect of the internal panel spacers, and variations in transmissivity with incident angle also need be considered.

For this installation, the variation in overall performance appears adequate, transmissivity increasing during the winter, decreasing during the summer. The overhang is responsible for a decrease in transmissivity during the summer up to a daily average of 14 percent.

Heat Pump

The heat pump operating time was greater than anticipated during this period. The Coefficient of Performance (COP) was a quite acceptable 2.9 during the heating season. The generation of the heating energy gave a net cost savings and the payback period was reasonable (11.4 years). Had the heat pump operating time equaled the projected operating time, the payback period would have been closer to 25 years, which is still reasonable.

The actual and projected hours of operation are based on present operating conditions. As the plant flow increases and digester gas production increases, the heat pump may be used less with an increasing payback period due to less operating time.

To date, the operation and maintenance problems encountered have been relatively small. A good deal of time, however, has been spent in cleaning the effluent strainers. Records should be kept for several years to determine realistic O&M costs for the system.

Generator Heat Recovery

The generator heat recovery loop operated approximately one half hour per week during the generator exercise period. During part of that time, the recovery loop was not used because the storage tank temperature was warmer than the maximum generator cooling heat exchanger allowed. Town water was then used to cool the generator. This condition will arise regularly during the summer when there is a limited heating demand and the active solar system is able to provide most of the heating required.

The generator could be exercised for longer periods of time during the heating season when digester gas is available.

The generator heat recovery loop has the highest energy output/input ratio, but the payback period is the worst. This is due to the low periods of use being experienced. Increased usage would increase cost-effectiveness.

Digester Gas Generation

The digester gas generation system is, from Table 1, an energy and value loser. However, process requirements must also be considered when evaluating this system.

Reflected Solar Radiation

The attempt to measure the magnitude of the ground reflected solar radiation component met with limited success. The reflected component for peak nonclear days was within the experimental accuracy of the equipment being used. The average daily reflected component consists of both reflected and some diffuse solar insolation. Thus no meaningful data on the magnitude of the reflected componenet were gathered. Part of the reason for this was the minimal snow cover experienced during the winter of 1979-80.

Electrical Usage

Even with the heat pump operating more and the generator operating less than anticipated, the total electrical usage has been 12.5 percent less than projected.

ENGINEERING EVALUATION

Several areas have been recognized where design modifications might significantly improve the performance of the energy system.

Hydronic Solar System

The solar heating system should be designed to supply thermal energy to heat the digester only, not be part of an integrated space/process heating system. While theoretically more efficient, the operating difficulties associated with a highly integrated system result in significant system losses. The following guidelines apply:

a. The solar system should be designed to service the digester directly with a glycol loop through the sludge heat exchanger.

b. The solar system should be designed to "dump" excess heat into the secondary digester and/or a storage tank. A heat exchanger should be provided to recover heat from sludge transferred from the primary digester to the secondary digester and/or from sludge wasted from the secondary digester.

c. The solar/sludge heat exchange system should be designed to operate with service fluid temperature of 43° to 46°C. The effectiveness of solar thermal energy collection improves significantly with lower operating temperatures.

d. The ratio of solar collector surface area in m^2 to sludge flow in m^3/d should be approximately 25:1 (i.e., 10 m^3/d of sludge requires 250 m^2 of solar collector surface), assuming climatic conditions similar to Wilton and digester insulation of R-20.

e. A conservative evaluation of expected sludge flow should be used in sizing the solar collector array. Generally, sizing should be based on average flow over the design life, or less.

f. Solar heating system design details:

1. The collector should be a flat plate design.

2. The collector tilt angle should be optimized for maximum yield approximately 45 days prior to and following winter solstice.

3. Systems capable of digester heating with fluid temperature of 43° to 46°C should use single glazing.

4. Systems requiring digester heating fluid temperatures greater than 48°C should use double glazed collectors.

5. The solar collector must be a low mass, quick response collector with a selective surface of a/e = 0.95/0.10, where a/e is the ratio of absorptivity to emissivity.

6. The associated hydronic system instrumentation and controls must be designed to respond more quickly to the availability of useable solar energy. Generally this requires a simpler system design.

7. The solar collector array should be designed for thirty year operation without significant maintenance and no replacement.

g. The solar collector may form a roof under the following guidelines:

1. The collector absorber plate must be thoroughly thermally isolated from the building support structure.

2. All seals must be high temperature silicone or equivalent.

3. All metals must be compatible or dielectrically isolated.

4. The collector glazing elements must be capable of simple replacement.

5. The rear of the collector array should be within a heated space and be accessible from the interior.

6. The rear of the collector should have R-20 insulation.

7. The tilt angle should be a minimum of 45 degrees.

h. Domestic hot water required for plant personnel should be supplied through a takeoff heat exchanger on the main system.

As discussed below, it is doubtful that solar heating of anaerobic digester can be shown to be cost-effective under current accepted economic projections, or under any conceivable circumstances except for a small range of treatment plant sizes, perhaps 0.04 m^3/s to 0.10 m^3/s. However, if other factors (socio-political, regulatory, etc.) dictate, the above guidelines will assure the most cost-effective use of solar thermal energy for digester heating. It should be noted that advances in solar collector technology since 1975 have incorporated many of the above guidelines.

Passive Solar Heating

1. Passive heating should be applied to "occupied" areas such as the office and laboratory. It is less effective in areas exposed to water surface such as Wilton's clarifier room, but may be desirable for natural lighting purposes. Such areas should be heated minimally, with thermostats set at 5°C. The movement of wastewater in these areas will largely maintain temperatures greater than 5°C.

2. In areas to be heated to 20°C±, passive solar collectors should be fitted with manually operated insulated shutters.

Heat Pump

The effluent pick up tank should be sized to minimize drawdown problems associated with plant flow variations and designed to facilitate maintenance of intake screens.

Instrumentation

Keep instrumentation as simple as possible. The instrumentation tends to become complicated when integrating solar and other alternative energy systems with the heating, ventilating and processes of the treatment plant.

Digester Gas System Design

The Wilton wastewater treatment plant's energy systems design has received a great deal of attention. Since the inception of the energy systems monitoring project, reports have been written concerning the economic feasibility of solar-assisted anaerobic sludge digestion (3,4). It is the author's opinion that some of these reports are overly optimistic and that the operating results at Wilton do not justify this optimism.

The basis for the Wilton design is that the use of flat plate hydronic solar collectors in concert with anaerobic sludge digestion is symbiotic, that the low temperature thermal energy produced by the solar collectors can be used to heat the digesters, replacing a portion of the digester gas produced which would have to be burned to heat a similar nonsolar-assisted digester. The gas thus replaced can be stored for use as a fuel for the production of direct thermal energy (boiler), electrical energy (engine-generator), or mechanical energy (engine-drive). The cost-effectiveness of active solar energy production is strengthened when so combined with anaerobic digestion. Its payback is quicker because the thermal energy is needed year-round to heat the sludge. Storage of solar energy is much more efficient in the form of the compressible, combustible, gas produced as a byproduct of digestion than as hot water or air. This is the rationale advanced to support the Wilton design and used to substantiate claims of widescale cost-effective applicability in other reports.

The problem with the solar digester scenario is in its cost-effectiveness; Wilton successfully demonstrates its technological feasibility. The evidence from Wilton and elsewhere indicates, however, that the payback on active solar systems is longer than anticipated due to actual operating efficiencies being significantly lower than projected from instantaneous design data efficiencies.

The other major flaw in the solar digester scheme is that heat can be recovered, directly or indirectly, from the digester gas more cost-effectively than by using solar. A study done by Wright-Pierce (5) to determine possible innovative and alternative technologies for use at a wastewater treatment plant being designed for Caribou, Maine indicates that if there is sufficient sludge to justify anaerobic digestion as a stabilization process, then it is more cost-effective to 1) burn the gas to heat the digesters; 2) use the gas to fuel an engine-generator set to produce electricity and recover the heat given off by the engine to provide digester heating; or 3) fuel an engine-drive set to operate equipment (replacing electricity), with engine heat recovery. If sludge digestion is justified, then the heat recovered from any of the above systems will be much more significant than any feasible solar contribution. If there is not sufficient sludge to make anaerobic digestion cost-effective, then adding solar will not make it so (this is Wilton's situation).

Wright-Pierce's report to EPA on the Wilton Energy Monitoring project evaluated the cost-effectiveness of solar heated anaerobic digestion for a range of treatment plant sizes (6). The conclusions from this analysis of anaerobic digestion, with and without solar heating, compared with lime stabilization for sludge processing were:

1. For wastewater treatment plants the size of Wilton's (1730 m^3/d), anaerobic digestion is not cost-effective and adding solar heat makes it even less so.

2. For a 3785 m^3/d wastewater treatment plant, anaerobic digestion is marginally cost-effective, but adding solar heat does not improve its cost-effectiveness and in fact makes lime stabilization more cost-effective.

3. For larger plants (37,850 m^3/d), anaerobic digestion is clearly cost-effective; and there is no use for solar heating, because all heating requirements can be met with waste heat recovery from the use of digester gas.

It appears that there is no role for solar heating in association with anaerobic digestion. Based on work done by others (4), if solar heating is not cost-effective when applied to anaerobic digestion, it is doubtful that it is cost-effective with any wastewater treatment process. It should be noted that no attempt has been made here to consider climatic conditions other than those encountered in Wilton, Maine, or other treatment processes. However, it is doubtful that solar heating of anaerobic digestion can be shown to be cost-effective in any climate, regardless of primary and secondary treatment processes used.

The analysis indicates that the price of conventional energy (oil, electricity) will have to increase substantially more than projected and the cost of solar heating substantially decrease before solar heating of anaerobic digestion can become cost-effective, and then only for a relatively insignificant number of small wastewater treatment plants; those large enough for anaerobic digestion to be cost-effective compared to other sludge stabilization methods, but too small for the gas produced to be sufficient to render the plant thermally self-sufficient.

Non-economic (socio-political, regulatory) factors may mandate a greater use of solar thermal energy, in which case solar heating of anaerobic digesters may be justifiable for small facilities. The argument has been made that solar should be incorporated into wastewater treatment plants, because it is an environmentally compatible "soft" energy source and is independent of factors which might interrupt the supply of conventional fuels. The reasoning is that if there is a sudden curtailment of conventional energy supplies, public facilities such as wastewater treatment plants probably would be among the first to be cut off. Therefore, incorporation of solar energy and other alternative energy sources safeguards the operation of the treatment facility and the resultant environmental protection.

By far the most energy used in wastewater treatment is electrical energy to run equipment. Even if solar heating could be shown to be cost-effective, the impact on total energy use in treatment plants would be relatively insignificant.

CONCLUSIONS

The results of the monitoring data analysis and engineering evaluation of the energy systems at the Wilton, Maine wastewater treatment plant have led to the following conclusions:

1. Wastewater treatment plant effluent heat recovery, through the use of a water-to-water heat pump is cost-effective under relatively severe temperature conditions.

2. Ventilation air heat recovery is cost-effective.

3. Generator cooling loop heat recovery may be cost-effective if increased use of the generator is warranted.

4. Passive solar heating, although not cost-effective as analyzed for the Wilton plant, can be made cost-effective with design modifications.

5. Solar system instantaneous efficiencies, when applied to clear day insolation levels and the mean expected percent sunshine, may lead to an overly optimistic evaluation of the actual long-term performance. These losses are related to the system threshold insolation intensity and the random weather patterns. It would, therefore, appear that computer simulation, using averaged hourly weather data and system performance criteria, is required to accurately estimate the long-term efficiencies. Moreover, since the threshold intensity level is predominantly affected by the difference in the average collector fluid and ambient temperatures, the long-term efficiency may be significantly reduced in northern climates.

6. Solar thermal energy collection for the purpose of producing supplemental heat for anaerobic sludge digesters is probably not cost-effective under currently accepted economic projections, regardless of size or location of the facility.

RECOMMENDATIONS

Based on the work done on the Wilton Treatment Plant monitoring project, the following are recommended:

1. A more realistic procedure must be developed for accurately estimating active solar heating system performance for the purpose of designing solar installations for space or process heating. Computer simulation models, taking into account site-specific hourly weather data, solar collector system response time, and inherent system losses should be developed to accurately evaluate alternative solar designs for cost-effectiveness during the preliminary design of a project. On-site weather data should be collected prior to the design phase to take into account site-specific microclimatology.

2. Although the it was concluded that solar heating of anaerobic digesters is probably not cost-effective, guidelines have been developed (see ENGINEERING EVALUATION) which should, if followed, significantly increase the efficiency of solar heating of digesters.

3. Passive solar heating of treatment plant structures can be cost-effective if applied to "occupied" areas such as the office and laboratory if good energy conservation principles are followed in the design of such areas. It is less cost-effective when applied to process areas exposed to water surfaces. In the latter case, it is important that room thermostats be set at 5°C, a temperature which can largely be maintained by the water passing through these areas. Combined with task heating (if necessary) and proper energy conservation design, passive solar heating and lighting can be cost-effective in process areas.

4. Effluent heat recovery through the use of a heat pump is cost-effective. Operational problems can be minimized by properly designing the effluent sump from which the heat pump draws to provide sufficient capacity at minimum plant effluent flows.

5. Instrumentation and controls should be simplified as much as possible. The theoretical advantages of integrated energy systems can be offset by complicated trouble-prone instrumentation.

6. The available evidence indicates that solar heating of anaerobic digesters is probably not cost-effective in accordance with the EPA guidelines, regardless of size of the treatment facility. There has been significant interest expressed throughout the United States in pursuing this concept under widely varying conditions of climate, process, size, etc. It is recommended, therefore, that EPA undertake modeling of the application of solar heating of anaerobic digesters to determine its cost-effectiveness under different conditions to determine if the conclusions drawn from the Wilton project can be generalized.

In the meantime, it is recommended that EPA not promote solar heating of anaerobic digesters and require detailed supporting documentation for any grantee requesting EPA Construction Grant Program funds for the design and construction of such facilities.

REFERENCES

1. Solar Heating Systems Design Manual. Training and Education Department, Fluids Handling Division, ITT Bulletin TESE-576.
2. Solar Heating and Cooling of Residential Buildings - Sizing, Installation and Operation of Systems. U.S. Department of Commerce, Economic Development Administration, Stock No. 003-011-00085-2.
3. Use of Solar Energy to Heat Anaerobic Digesters. EPA 600/2-78-114, NTIS No. PB 286940, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978.
4. Overly, P., and C. Franklin (Acurex Corp.) Solar Energy for Pollution Control. EPA Contract No. 68-03-2567, 1978.
5. Wright-Pierce. Conceptual Design Report, Grimes Mill Wastewater Treatment Plant, Caribou, Maine. 1979.
6. Fuller, D.R., D.A. Wilke, P.L. Thomas and A.J. Lisa (Wright-Pierce). Integrated Energy Systems Monitoring of Municipal Wastewater Treatment Plant in Wilton, Maine. EPA Contract No. 68-03-2587, 1981.

"This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication."

PLANT OPERATION AND DESIGN PROGRAM
Related Publications and Papers

December 1981

Areawide Assessment Procedures Manual. July 1976. EPA-600/9-76-014, *U.S. Environmental Protection Agency*, Cincinnati, OH. Order No. PB-271863/AS* (Set--3 Volumes)

Bender, J. H. March 1978. *Parallel Evaluation of Constant and Diurnal Flow Treatment Systems.* EPA-600/2-78-034, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-281401/AS*

Bender, J. H. January 1979. "The Oxidation Ditch Process: Superior Performance and Reliability at Low Cost," *Environmental Research Brief.* U.S. Environmental Protection Agency, Cincinnati, OH.

Benjes, H. J. December 1976. *Cost Estimating Manual - Combined Sewer Overflow Storage and Treatment.* EPA-600/2-76-286, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-266359/AS*

Benjes, H. H., J. A. Faisst, and T. S. Lineck. *Capital and O&M Cost Estimates for Biological Wastewater Treatment Processes.* August 1979. Draft Report, Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, Cincinnati, OH.

Chesner, W. H., and J. J. Iannone. February 1980. "Current Status of Municipal Wastewater Treatment with RBC Technology in the U.S.," In: *Proceedings: First National Symposium/Workshop on Rotating Biological Contactor Technology.* Volume I, EPA-600/9-80-046a, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-81-124539*

Collins, M. A., and R. M. Crosby. October 1980. "Impact of Flow Variation on Secondary Clarifier Performance," Presented at 53rd Annual Conference WPCF, Las Vegas, NV.

Construction Costs and Operation and Maintenance Requirements for Wastewater Filtration. Draft Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Costs of Chemical Clarification of Wastewater. Draft Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Crosby, R. M. *Evaluation of the Hydraulic Characteristics of Activated Sludge Secondary Clarifiers.* November 1981. Draft Report, Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, Cincinnati, OH.

Crosby, R. M., and J. H. Bender. March 1980. "Hydraulic Considerations That Affect Secondary Clarifier Performance," Technology Transfer. U.S. Environmental Protection Agency, Cincinnati, OH.

Efficient Treatment of Small Municipal Flows at Dawson, Minnesota. October 1977. EPA-625/2-77-015, U.S. Environmental Protection Agency, Cincinnati, OH.

Ettlich, W. F. December 1977. Transport of Sewage Sludge. EPA-600/2-77-216, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-278195/AS*

Ettlich, W. F. March 1978. A Comparison of Oxidation Ditch Plants to Competing Processes for Secondary and Advanced Treatment of Municipal Wastes. EPA-600/2-78-051, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-281380/AS*

Ettlich, W. F., and A. E. Lewis. August 1977. User Acceptance of Wastewater Sludge Compost. EPA-600/2-77-096, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-272095/AS*

Ettlich, W. F., and A. E. Lewis. June 1978. A Study of Forced Aeration Composting of Wastewater Sludges. EPA-600/2-78-057, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-285232/5BE*

Evaluation and Control of Sidestreams in Publicly Owned Treatment Works. July 1981. Draft Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Evaluation and Documentation of Mechanical Reliability of Conventional Plant Components. December 1980. Draft Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Evans, F. L. July 1979. "Summary of National Operational and Maintenance Cause and Effect Survey," Technology Transfer. U.S. Environmental Protection Agency, Cincinnati, OH.

Ewing, L. J., Jr., H. H. Almgren, and R. L. Culp. June 1978. Effects of Thermal Treatment of Sludge on Municipal Wastewater Treatment Costs. EPA-600/2-78-073, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-285707/AS*

Foess, G. W., J. G. Meenahan, and D. Blough. August 1977. Effects of Flow Equalization on the Operation and Performance of an Activated Sludge Plant. EPA-600/2-77-138, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-272656/AS*

Foess, G. W., J. G. Meenahan, and J. M. Harju. December 1976. *Evaluation of Flow Equalization at a Small Wastewater Treatment Plant. EPA-600/2-76-181, U.S. Environmental Protection Agency, Cincinnati, OH.* Order No. PB-260375/AS*

Gray, A. C., P. E. Paul, and H. D. Roberts. October 1980. "Operational Factors Affecting Biological Treatment Plant Performance," *JWPCF*, 52:7, pp 1880-1892.

Gray, A. C., P. E. Paul, and H. D. Roberts. July 1979. *Evaluation of Operation and Maintenance Factors Limiting Biological Wastewater Treatment Plant Performance.* EPA-600/2-79-078, U.S. Environmental Protection Agency, Cincinati, OH. Order No. PB-80-108947*

Gray, A. C., P. E. Paul, and H. D. Roberts. *Evaluation and Documentation of Operation and Maintenance Factors Limiting Biological Treatment and Plant Performance, Phase II.* Final Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Grover, K. October 1979. "Don't Blame the Operator," *American City and County.*

Handbook for Identification and Correction of Typical Design Deficiencies of Municipal Wastewater Treatment Facilities. October 1981. Draft Final Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Harber, A. F., and R. C. Bain. July 1979. *Novel Methods and Materials of Construction.* EPA-600/2-79-079, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-80-113681*

Hegg, B. A., K. L. Rakness, and J. R. Schultz. October 1977. "Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance," Presented at Rocky Mountain Water Pollution Control Association, Albuquerque, NM.

Hegg, B. A., K. L. Rakness, and J. R. Schultz. March 1978. "Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance," *JWPCF*, 50:3 pp. 419-426.

Hegg, B. A., K. L. Rakness, and J. R. Schultz. March 1978. "Summary - O&M Factors Limiting Wastewater Treatment Plant Performance," Presented at O&M Workshop - Steering Committee for the Joint U.S./Canada Great Lakes Commission.

Hegg, B. A., K. L. Rakness, and J. R. Schultz. October 1978. "Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Plant Performance - Phase II," Presented at 51st Annual Conference WPCF, Anaheim, CA.

Hegg, B. A., K. L. Rakness, and J. R. Schultz. June 1979. A Demonstrated Approach for Improving Performance and Reliability of Biological Wastewater Treatment Plants. EPA-600/2-79-035, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-300476/AS*

Hegg, B. A., K. L. Rakness, and J. R. Schultz. June 1979. Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance. EPA-600/2-79-034, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-300331/AS*

Hegg, B. A., K. L. Rakness, and J. R. Schultz. March 1980. "Evaluation of O&M Factors Limiting Wastewater Plant Performance," Pollution Engineering.

Hegg, B. A., K. L. Rakness, and J. R. Schultz. October 1980. "Case Histories - Improving Wastewater Treatment Plant Performance," Presented at 53rd Annual Conference WPCF, Las Vegas, NV.

Hegg, B. A., K. L. Rakness, J. R. Schultz, and L. D. DeMers. August 1980. Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance, Phase II. EPA-600/2-80-129, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-81-112864*

Hourly Diurnal Variations in Publicly Owned Wastewater Treatment Facilities. September 1981. EPA-600/2-81-218, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-107954/AS*

Lykins, B. W., Jr., and J. M. Smith. January 1976. Interim Report on the Impact of PL 92-500 on Municipal Pollution Control Technology. EPA-600/2-76-018, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-248212/AS*

McMahon, R. F. Socioeconomic Impacts of Water Quality Strategies. Final Report, Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, Cincinnati, OH.

Niehus, D. C. Incentives for Improved Operation and Maintenance of Municipal Treatment Plant. Unpublished Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Niehus, D. C., G. A. Brown, and J. M. Houthoofd. August 1981. "Survey of Private Sector Provision of Operation and Maintenance Services to Publicly Owned Treatment Works," Newsbrief. U. S. Environmental Protection Agency, Cincinnati, OH.

Niku, S., E. D. Schroeder, and F. J. Samaniego. December 1979. "Performance of Activated Sludge Processes and Reliability Based Design," JWPCF, 51:12, pp 2841-2857.

Niku, S. and E. D. Schroeder. April 1981. "Stability of Activated Sludge Processes Based on Statistical Measures," *JWPCF*, 53:4, pp 457-470.

Niku, S. and E. D. Schroeder. May 1981. "Factors Affecting Effluent Variability from Activated Sludge Processes," *JWPCF*, 53:5, pp 546-559.

Nitrogen Removal in a Flow Modulated, Single State Oxidation Ditch. Draft Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Ongerth, J. E. May 1979. *Evaluation of Flow Equalization in Municipal Wastewater Treatment.* EPA-600/2-79-096, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-80-139835*

Operation and Maintenance Considerations of Land Treatment Systems. July 1981. Draft Final Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Performance of Activated Sludge Processes: Reliability, Stability, and Variability. September 1981. EPA-600/2-81-227, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-109604/AS*

Performance of Biological Wastewater Treatment Plants: Effects of Toxic Pollutants. September 1980. Draft Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Performance of Trickling Filter Plants: Reliability, Stability, and Variability. September 1981. EPA-600/2-81-228, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-108143/AS*

Review of RBC Design Procedures, and Process, O&M, Equipment and Power Performance. September 1980. Draft Report, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Roberts, H. D., A. C. Gray, and P. E. Paul. *Model Protocol for the Comprehensive Evaluation of Publicly Owned Treatment Works Performance and Operation*. May 1982. EPA 600/2-82-015, NTIS No. PB 82-180 480, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Schultz, J. R., B. A. Hegg, and K. L. Rakness. October 1980. "Realistic Sludge Production for Activated Sludge Plants Without Primary Clarifiers," Presented at 53rd Annual Conference WPCF, Las Vegas, NV.

Smith, J. M., F. L. Evans III, and J. H. Bender. May 1980. "Improved Operation and Maintenance Opportunities at Municipal Treatment Facilities," Presented at 7th U.S./Japan Conference on Sewage Treatment Technology.

Wesner, G. M. November 1977. Energy Requirements for Municipal Pollution Control Facilities. EPA-600/2-77-214, U.S. Environmental Protection Agency, Cincinnati, OH. Order No. PB-276989/AS*

Wesner, G. M., G. L. Culp, T. S. Lineck, and D. J. Hinrichs. June 1978. Energy Conservation in Municipal Wastewater Treatment. EPA-430/9-77-011 (MCD-32), U.S. Environmental Protection Agency, Washington, DC. Order No. PB-81-165391*

---

*Available from: National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

☆USGPO: 1983 — 759-102/0788